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Effects of subsurface drainage on productivity of western larch and nutrient content of andic soils in northwestern Montana

Charles E. Spitzner
The University of Montana

THE EFFECTS OF SUBSURFACE DRAINAGE ON PRODUCTIVITY OF WESTERN LARCH AND NUTRIENT CONTENT OF ANDIC SOILS IN NORTHWESTERN MONTANA

By

Charles E. Spitzner, Jr.

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Approved by:

Nellie M. Stark
Chairman, Board of Examiners

Dean, Graduate School

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Low nutrient content and productivity were observed in andic soils of northwestern Montana. The objective of this research was to determine whether variation in subsurface drainage rate significantly affected (1) the nutrient content of the andic soils, or (2) the timber productivity of andic soils.

Twenty sample sites supporting stands of western larch (*Larix occidentalis* Nutt.) were selected on the Kootenai National Forest. Grouping of sites was based upon subsoil percolation rates and Forest Service land type classification. Soil nutrient concentrations and availabilities, tree growth indicators, xylem sap nutrient contents, and tree moisture stresses were utilized as indicators of soil fertility and productivity.

The results of this study indicated support of the hypothesis that the rate of subsoil drainage affected the overall fertility of andic soils. Tree growth and site productivity were affected by the subsoil drainage rate as it related to moisture availability.

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INTRODUCTION

Andic soils in northwestern Montana have developed from volcanic ash deposited following the eruption of Mount Mazama (site of present day Crater Lake, Oregon) about 6,600 years ago (Allison 1966, Kittleman 1973). Other ash falls following the eruptions of Glacier Peak about 11,250 years ago (Mehringer *et al.* 1977) and the intermittent eruptions of Mt. St. Helens beginning 35,000 years ago (Crandell and Mullineau 1973) contributed minimally to ash in these soils. The quantity of tephra deposited in Montana from these sources is small by comparison to that from Mt. Mazama, and has contributed less to andic soil development.

Soils developing from volcanic ash material exhibit a high cation exchange capacity and water holding capability (Fosberg *et al.* 1979, U.S.D.A. Forest Service 1972, Will and Stone 1967). Inherent fertility and greater than average forest productivity are expected on soils exhibiting these characteristics. Poor forest growth on andic soils in areas of northwestern Montana receiving greater than 76 cm of annual precipitation is inconsistent with management expectations. When affected acreages are large, the poor growth becomes cause for concern.

The St. Regis Paper Company operation in Libby, Montana, controls hundreds of acres of land in the Lake Creek drainage which exhibit poor timber growth on ash influenced soils. Studies completed in this valley (Stark 1977, Stark and Spitzner 1980) have exposed apparent multiple nutrient deficiencies in the andic material on several sites. The occurrence of these deficiencies appears to coincide with the presence of excessively well drained subsoils. Andic soils overlying more slowly drained lacustrine sediments tend to exhibit higher fertility and productivity than expected.

Moisture stress measurements were made on several sample trees (*Tsuga heterophylla* (Raf.) Sarg.) growing on nutrient deficient andic soils in the Stanley Bottoms area north of Bull Lake (Stark and Spitzner 1980). Levels of stress were much higher for these trees than for western hemlocks growing on a moister site nearby.

The nutrient deficiencies and moisture stress encountered gave rise to the supposition that the forest productivity of andic soils might be related to the drainage characteristics of the subsoils.

Because many areas of federally managed land in northwestern Montana exhibit low productivity on andic soils, the United States Forest Service became interested in exploring this hypothesis further. The Kootenai National Forest, headquartered in Libby, Montana, obtained funding to examine the relationships among drainage, productivity, and nutrient status of sites having soils derived from volcanic ash.

RESEARCH OBJECTIVES

The objective of this research was to examine two hypotheses concerning soils having volcanic ash layers in the Libby area of northwestern Montana. The first hypothesis supposed that the fertility of soils having volcanic ash caps, as measured by the levels of available soil nutrients, is affected significantly by the rate of percolation of water through the subsoil.

The second hypothesis presumed that the rate of water percolation through the subsoil significantly affects timber productivity on sites having andic soil layers, either as a result of lowered nutrient fertility or through moisture status of the soil. The indicators of timber productivity used were the thickness of sapwood (Lassen and Okkonen 1969, Smith *et al.* 1966), the ratio of basal area to sapwood area (Waring *et al.* 1980, Grier and Waring 1974), and site index (Carmean 1975). The timber species chosen for study was western larch (*Larix occidentalis* Nutt.).

LITERATURE REVIEW

Soil Site Studies

This review does not attempt to include every study devoted to soil-site relationships. Through the years Gaines (1948), Coile (1952), Carmean (1975), and several other authors have done this. What is presented here is an overview of the work that has been completed.

Very little information is available in the literature concerning the nutrient relations and productivity of andic soils, either pertaining to the northwestern United States or to the western larch (*Larix occidentalis* Nutt.) species.

Studies investigating subsoil percolation and its effect on the fertility and productivity of volcanic ash soils are lacking in the literature. Site factor - tree growth relationship studies on various timber species and in various parts of the country have examined the effects of drainage, elemental content, and other factors on the productivity of numerous sites. The results of these investigations give an indication of the effects to be expected from the interactions of percolation, nutrient content, and other related soil factors on timber productivity. The preponderance of the soil-site studies express site productivity in terms of site index. In some cases, however, other methods of expression for growth or productivity correlate more significantly with soil factors.

Voigt (1958) has attributed the failure of many soil-site studies to show relationships between soil chemical properties and site productivity to the similar levels of fertility often encountered on many sites. If levels of fertility are adequate to support good growth, other factors must necessarily become the determinants for growth limits. Voigt also concludes that in soils, the same factors that tend to regulate the availability of nutrients are often the same factors which govern the availability of water. Growth responses which appear to be the result of a moisture or nutrient limitation may actually be attributed to a combination of masked conditions affecting moisture or nutrient status.

White (1958) contended that the key factor in forest site productivity evaluation is soil moisture. He further stated that most site classification schemes were simply schemes to indirectly characterize the soil moisture regime.

According to Coile (1952) the quality of a site as a timber producer was largely determined by the characteristics of that site which influence the amount and quality of the space available to roots for growth. The site features which he considered to be most important to site productivity as they affected root growth were: (a) depth of surface soil, depth to the least permeable horizon, or depth to mottling; (b) total depth of soil as a measure of growing space; (c) physical nature of the subsoil, least permeable layer, or substratum as it influences water movement, water availability, aeration, and root growth; (d) physical properties of the surface soil as they influence infiltration and water storage; (e) organic matter content as it influences moisture status, porosity, and aeration; and (f) chemical characteristics as they affect nutrient supply.

Lutz and Chandler (1946) and Nikiforoff (1949) concurred that in a single climatic environment, the soil parent material was the most important factor determining variation in site productivity. Hough (1943) determined that soils derived from shale were more productive than those developed from conglomerates or sandstone on the northern Allegheny Plateau in Virginia. Vlamis *et al.* (1959), working in California, found that soils developed from conglomerates composed of shale and sandstone supported better growth of ponderosa pine (*Pinus ponderosa* Laws.) than did soils from volcanic ash. Granitic soils were the least productive of the three examined.

Shrivastava and Ulrich (1978), working on stands of Norway spruce (*Picea abies* Karst.) in the Hesse Province of the Federal Republic of Germany, determined that available water supply accounted for 57% of the variation in timber growth among sites. Nutrient status and the presence of humus accounted for an additional

15% of the variation, with topography (4.5%), rainfall during the growth period (4.2%), and soil aeration (2.3%) also contributing significantly.

Page (1976) found that soil moisture regime, expressed in terms of sand, silt, and clay contents, depth of humus accumulation, organic matter content of the soil profile, percent moisture retention, and other variables, was the most important site characteristic in determining projected site index for stands of black spruce (*Picea mariana* (Mill.)sp.B.) and balsam fir (*Abies balsamea* (L.) Mill.) in Newfoundland. Qualitative factors such as soil type, profile drainage, and site drainage were strongly correlated with one another and with site index. Well drained sites and free or moderately drained profiles supported the best forest growth in these timber types.

Lowry (1972), in a study of black spruce in the Atlantic and Continental regions of eastern Canada, concurred as to the importance of soil moisture to site productivity, and determined that soil nutrient content was also well correlated to site index. Free drainage of site was as important in these regions as it was in Newfoundland (Page 1976).

The greatest number of soil-site quality studies in the United States has been centered in the areas of the country where timber management has been the most intense. To date, that intensity has been concentrated in the south and southeast, the northeast, and the north central regions of the country. The past ten to twenty years have brought an increase in management intensity in the southwest and northwest regions, and an accompanying increase in concern for relating soil and site factors to timber productivity on a site.

Coile (1948), working in the lower piedmont area of North Carolina, linked the site index of loblolly (*Pinus taeda* L.) and shortleaf (*P. echinata* Mill.) pines to the thickness of the A horizon, the ratio of silt-plus-clay to the moisture equivalent of the B horizon, and the imbibitional water value of the B horizon or subsoil. Site index for these species in southern Arkansas and northern Louisiana was similarly determined by Zahner (1958) to be highly correlated to site factors which contributed to the regulation of soil moisture and aeration.

The net primary productivity (kg/tree per year of growth) of loblolly and slash pine plantations on the coastal plain of North Carolina was examined by Nemeth and Davey (1974). Physical characteristics of the soils of all sites sampled were comparable and, predictably, were not significantly related to variation in tree growth. Chemical differences among the plantation soils were correlated with variation in productivity. In the loblolly plantations the exchange acidity, cation exchange capacity, pH, and exchangeable magnesium and potassium contents were significantly interrelated and linked to site productivity. In the slash plantations only the cation exchange capacity correlated with productivity among sites.

Using the field, laboratory, and analytical techniques developed by Coile (1948) in North Carolina, Young (1954) correlated site index of white pine (*Pinus strobus* L.) in Maine to two moisture availability controlling factors: percent stones in the B horizon and thickness of the A horizon. His results were the opposite of those obtained by Coile (1948) in that, as the thickness of the A horizon and the percentage of stones in the B horizon increased, site index decreased. Young could not explain the difference in results from the data on hand, but hypothesized that it was caused by the overall decrease in soil moisture holding capacity with the increase in stoniness.

Later work by Stratton and Struchtemeyer (1968) in white pine linked site index decreases to increased stoniness in the C horizon. Significant increases in site index accompanied an increase in thickness, soil moisture availability, and stoniness in the surface horizon. Decreases in site index were related to higher pH levels in the surface mineral horizons.

Husch and Lyford (1956) examined the average height of dominant and codominant white pines in southeastern New Hampshire. The soils of the sample sites represented the whole range of soil conditions to be found throughout the white pine region of New England. The primary source of variation in average height growth appeared to be soil drainage. For the seven drainage classes included in the sampling, the average tree height increased one foot (30.5 cm) with each change in soil drainage from excessively drained to poorly drained. In addition, the diameter of measured trees increased approximately 0.013 inches (0.33 cm) with each 1 foot (30.5 cm) height increase due to a change in drainage class.

A white pine study by Mader (1976) in Massachusetts indicated better correlation between site productivity and soil factors using periodic cubic volume growth rather than site index as a measure of productive capacity. Volume growth was enhanced by increases in silt and clay in the A horizon, and reduced by like increases in the B horizons. This was apparently associated with better moisture and nutrient availability in the former, and reduced aeration and root growth in the latter. Higher pH levels in the B or C horizons resulted in increased tree growth.

In a study evaluating foliar nutrient concentrations in balsam fir, Czapowskyj (1979) noted that soil drainage affected the uptake of nitrogen, potassium, and manganese. Lower concentrations of all three elements were present in the foliage of trees grown on poorly drained sites. This relationship held on soils developed in both glacial till and marine sediments.

Stout (1952) conducted a study of the species distribution of eastern hardwoods as related to the texture of subsoils derived from glacial till. Well-drained upland hardwood sites, underlain by compact glacial till containing large amounts of fine sands and silt, support the growth of mixed hardwood species characteristic of moister sites. Sites underlain by coarse, loose, glacial till were found to support growth of only the more xerophytic species. The differences in species composition appeared related to the ability of the glacial till material to support a perched water table through part of the growing season.

Mader and Owen (1961) conducted a soil-site study on red pine (*Pinus resinosa* Ait.) plantations in Massachusetts in which the five-year cubic foot volume expressed the site productivity better than height increase over ten years, height at age 25, or volume per acre at age 25. Nitrogen and organic matter content of the soil and drainage class were found to be highly significant in accounting for variation in the volume growth rate.

Mean growth rate and site index of red pine growing in plantations in Michigan were examined by van Eck and Whiteside (1963) for relationships to different soil series. Much of the variation in site index and mean growth rate within any one soil series was explained by small variations in the physical make-up of the surface horizons, quality of planting stock, and allowable series' ranges in soil properties. Variations within soil series were best correlated to factors affecting soil moisture supply and limiting the effective depth of the soil.

In Minnesota red pine stands Alban (1974) identified soil moisture availability as important in determining site index not only in terms of water supply for growth, but also as it affects the rate of nitrogen mineralization. Soils having the better moisture availability exhibited the highest nitrogen availability in areas where nitrogen was a major limiting factor for tree growth. Growth limitations induced by nutrient deficiencies were found to be more common than previously supposed. Nitrogen was the nutrient most closely related to site index, with phosphorus gaining importance on sites containing adquate nitrogen.

White and Wood (1958) examined two red pine stands which exhibited marked growth differences. Chemical and physical properties of the solum to a depth of six feet were comparable in both cases. Potassium in the soil of both stands was low. The soil supporting good growth of red pine was underlain by a deep, silty, fine sand layer which apparently provided additional water and potassium. Height growth of the good stand was 60% greater than that of the poor stand.

In red pine plantations in Wisconsin Wilde (1965) determined that the nutrient content of soils could be of decisive importance, and that dependence solely on physical and morphological soil factors to explain forest growth variation could be deceptive. His study results indicated that a 50% decrease in the supply of organic matter, phosphorus, and potassium in an acid sandy soil will lower the site index of a thirty-year-old plantation from 67 to 55, with a corresponding reduction in total timber yield of 40%.

Attempting to establish a correlation between growth of mixed oak stands and various soil factors in southwestern Wisconsin, Youngberg and Scholz (1949) sampled a number of different soil types. The rate of forest growth was conspicuously correlated with the content of the total replaceable bases, apparently reflecting the relative abundance or deficiency of soil nutrients. On deeply weathered soils a close correlation was also observed between the contents of organic matter and the base exchange capacity.

Pawluk and Arneman (1961) noted rapid site index increase with an increased water holding capacity of the soil in stands of jack pine (*Pinus banksiana* Lamb.). The relationship held true up to a certain level of water holding capacity, after which no further increase in site index was apparent. The upper threshold varied with site. Soil fertility was also linked to site index in these stands. Levels of the exchangeable metallic ions, calcium, magnesium, and potassium, and the total cation exchange capacity of the solum correlated significantly with site index.

Hannah and Zahner (1970), working with jack pine and bigtooth aspen (*Populus grandidentata* Michx.) in Minnesota, found that coarse textured soils, having lenses of fine textured materials within one meter of the surface, produced site indices significantly higher than soils without the lenses, or with lenses at depths greater than two meters. The lenses appeared to serve as depositories of additional moisture and nutrients, important for good growth on these coarse soils.

In mature quaking aspen (*Populus tremuloides* Michx.) stands Fralish and Loucks (1975) could account for 62% of the site index variation by examining soil texture, available water holding capacity, water table depth, and stand exposure. Magnesium content of the solum to a depth of 60 inches (152.4 cm) also correlated to site index.

Gilmore (1976) noted a significant relationship between the chemical composition of the soil and tree diameter and height growth in stands of cottonwood (*Populus deltoides* Bart.) in southern Illinois. Nitrogen and calcium were the nutrients best correlated with diameter growth, each accounting for approximately 33% of the variation. Only nitrogen content of the soil was related significantly to tree height growth, explaining 37% of the sample variation. Gilmore concluded that the effect of calcium on tree growth was likely the result of its ability to raise soil pH on sites where its concentration was highest. The rise in pH created a more favorable environment for soil microorganisms.

Auten (1945) was unable to correlate site index of yellow poplar (*Liriodendron tulipifera* L.) to soil pH or levels of calcium, magnesium, phosphate, or potassium. His work determined that the depth to tight subsoil was the most important soil factor in explaining growth differences. The thickness of the upper organic-enriched mineral horizon in undisturbed stands was also significant in the soil-site relationship, but only when depth to tight subsoil was included as a factor.

Williams *et al.* (1963) examined the soil factors influencing the growth and productive capacity of sites supporting ponderosa pine in the Zuni Mountains of New Mexico. Factors significantly correlated with site index were fertility, water holding capacity, permeability of the A horizon, and depth of the permeable soil.

In stands of Engelmann spruce (*Picea engelmannii* Parry) on granitic soils in northern Colorado and southern Wyoming, Sprackling (1973) determined soil depth to the top of the C horizon to be the most important factor in predicting site index, accounting for 52% of the total variation among sites. The real value of soil depth as an indicator of soil productivity was considered to be its function as an integrator of the climatic factors affecting height growth; i.e. precipitation and temperature.

In a study of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) soil fertility, Tarrant (1949) concluded that soil nutrient levels in western Washington were too high to be limiting factors for tree growth.

Hill *et al.* (1948) noted that Douglas-fir growing on sites in western Washington seemed to be limited in growth by the moisture relationships of the soil. For stands growing on the same soil type, a higher site index correlated with increased precipitation.

Gessel (1949) concurred with the findings of Hill *et al.* (1948). He stated that site index for Douglas-fir in northwestern Washington increased with change in soil texture from coarse to light to medium. He also found that medium textured soils did not differ significantly in site productivity, even when soils having different profiles were examined. The overall depth of the soil was an important factor in tree growth for sites underlain by a hardpan or bedrock.

In a study on Douglas-fir growth and site index in southwestern Washington, Carmean (1954) reported site quality decreases with increased elevation and with increased gravel content or compaction above the substratum. He suggested that the decrease in productivity with elevation may come about as a result of temperature induced delay in the onset of growth until the period of decreased summer precipitation. Again, increases in effective soil depth resulted in increased site index.

Forristall and Gessel (1955) examined stands containing Douglas-fir, western redcedar (*Thuja plicata* Donn), and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) in western Washington. Depth to a hardpan layer appeared to be the most important factor limiting tree growth. The high bulk density associated with the hard pan limited root growth and determined the effective soil depth. The more productive sites had a higher concentration of total nitrogen and a higher cation exchange capacity.

Schlots *et al.* (1956) concurred that for Douglas-fir in western Washington the depth of soil to a claypan, fragipan, or hardpan was closely related to site quality. They further noted that strong profile development or degree of horizonation resulted in progressively lower timber site productivity. On soils exhibiting similar profile development, stand growth was comparable, regardless of parent material.

Tarrant (1950) studying soil-site relationships in Douglas-fir stands in Oregon could not explain site quality differences on the basis of soil factors. He did note that topography was significantly related to productivity. Concave topography consistently produced better timber growth in each soil type examined and in the study as a whole as compared to convex topography.

Studying Douglas-fir in the Willamette Basin of Oregon, Lemmon (1955) concluded that, as in Washington, the productive capacity of a soil was determined primarily by the effective soil depth.

Grand fir (*Abies grandis* (Dougl.) Lindl.) productivity in northern Idaho was found to be related strongly to topography and the depth, texture, and color of volcanic ash soils overying buried soils of the Belt Series (Wall and Loewenstein 1969). Calcium and potassium contents also appeared significantly related to productivity, but the authors cautioned against excessive dependence upon them in predicting site quality. The quantity of these elements necessary for good tree growth in grand fir stands is still undetermined.

Regression equations were developed by McGrath and Loewenstein (1975) on the University of Idaho experimental forest for use with Douglas-fir, western larch (*Larix occidentalis* Nutt.), and grand fir. Dependable results were obtained using elevation, effective rooting depth, wet consistence of the second horizon, and texture of the third horizon to predict growth of Douglas-fir. The pH of the fourth horizon and the depth of the 02 horizon produced acceptable prediction of site index for western larch. For grand fir the organic matter and nitrogen percentages and the dry color of the surface horizon, together with the magnesium content (milliequivalents/100 grams) of the second horizon, gave the best results.

Cox *et al.* (1960) noted a significant correlation between tree growth in ponderosa pine stands and the effective depth of the soil for root development in work done in Montana, west of the Continental Divide. Effective depth of soil was limited consistently by four factors: (a) depth to gravel or loose sand, (b) depth to a slowly permeable layer, (c) depth to bedrock, and (d) depth to lime.

Work in the Clark Fork River Valley between Thompson Falls, Montana, and the Idaho border by Carlson and Nimlos (1966) examined stands of western larch, ponderosa pine, Douglas-fir, and lodgepole pine (*Pinus contorta* Dougl.) in relation to soil series designations. Significance levels were highest for western larch and ponderosa pine, but for all four species site indices were among the highest in Montana. Site indices were also significantly different within all species groups over the range of soil series. The conclusion was drawn that soil series could be used to determine or predict site index for the four species studied within the study area.

Embry (1960) sampled soils from 45 sites in western larch stands throughout northwestern Montana in an effort to establish soil-site quality relationships. Of the soil factors measured, only effective soil depth proved significant in predicting height growth for the stands examined.

In a soil-site study of western larch on soils of the Waits series in the Swan Valley of western Montana, Pearcy (1965) noted that none of the soil or physiographic factors examined were significant in the determination of site index on the sample sites. He concluded that the variation in these factors within the study area was too limited to relate significantly to variation in height growth of western larch.

Sapwood and Productivity

The use of sapwood production in coniferous species of the western United States as a measure of site quality is a technique which, though recognized as practical for over two decades, has been little utilized in the field. Researchers have begun using the measure of sapwood width alone or the sapwood-area/basal-area ratio as a means of evaluating the productivity of a soil or site for various timber species.

Wellwood (1955) determined that the thickest sapwood in Douglas-fir was associated with the most vigorously growing trees. Wellwood and Jurazs (1968) and Smith *et al.* (1966), working in stands of western redcedar and Douglas-fir, respectively, concurred that thickness of sapwood and relative tree vigor vary directly. They also concluded that sapwood thickness generally increases with tree diameter, rate of growth, bark thickness, and relative crown size. Wellwood and Jurazs (1968) further determined that no significant difference was observable between sapwood thickness determined by a single radial measure (as obtained by increment coring), and the thickness measurement resulting from the averaging of four quadrant radial measurements.

Lassen and Okkonen (1969) noted that Douglas-fir on Washington's west coast have wider sapwood than comparable sized trees further inland. The fact that trees on the west coast reached given diameters at a younger age than those growing inland supported the conclusion that sapwood width could give reliable indication of tree vigor and site productivity. Average sapwood width in western larch was found to vary little in trees having diameters of 5 to 22 inches (12.7-56 cm) inside bark at breast height (4.5 feet, 1.37 m).

In an effort to find a simple method of determining foliage mass for individual trees of large size or great age, Grier and Waring (1974) compared sapwood area and diameter at breast height to foliage mass for individual Douglas-fir, ponderosa pine, and noble fir (*Abies procera* Rehd.) trees. Linear relationships were established and sapwood area appeared the better estimate of foliage mass. A similar relationship (Ovington *et al.* 1968) was shown to exist between foliage mass and bole cross-sectional area in young Monterey pine (*Pinus radiata* D. Don). Cross-sectional area in Monterey pine is comparable to sapwood area plus bark, as its heartwood begins to form only after nineteen to twenty years (Nicholls and Dadswell 1965).

Snell and Brown (1978) examined both the sapwood area and diameter at breast height relationships to foliage and branchwood biomass for Douglas-fir, western white pine (*Pinus monticola* Dougl.), western redcedar, grand fir, subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), and western larch. Results of the investigations indicated that for Douglas-fir and western white pine the estimates of biomass provided by sapwood area were significantly better than those obtained using diameter. Variation between the estimates produced by the two methods for western redcedar, grand fir, subalpine fir, and western larch was not significant. Brown (1978) determined that the small amount of improvement in estimation of branchwood biomass using sapwood area as opposed to diameter at breast height did not justify the extra work necessary to obtain the additinal measurements.

METHODS

Study Area

The original intent of this study was to continue the examination of soils having andic layers in the Lake Creek Valley. Lake Creek rises in Bull Lake, nineteen kilometers south of Troy, MT, and empties into the Kootenai River to the east of town. The difficulty involved in locating sample sites in this area which could be meaningfully related to areas of concern on the Kootenai National Forest resulted in a change of location for this research.

Consultation with staff members of the Kootenai National Forest Supervisor's Office in Libby determined that the headwaters area of Seventeen Mile Creek would be more representative of the forest as a whole. The study was relocated to this area, approximately twenty-five kilometers to the NNW of Libby. The proposed hypotheses were formulated for the Lake Creek Valley soils in which the volcanic ash horizons appear to have been reworked by water movement. Notice was taken at the time of study area relocation that the changes in andic soil characteristics associated with the change in location might produce results inconsistent with those from soils in the Lake Creek Valley.

Drainage

Brady (1974) defines soil drainage as being a condition which refers to the frequency and duration of periods that the soil is free of saturation. In well-drained soils the water is removed readily but not rapidly, while removal is so complete in excessively drained soils that plants may suffer from lack of water. Brady considers percolation to be the downward movement of water through the soil, especially at or near a saturated condition.

In this research, reference is often made to soil drainage rate. As used here it is intended to be synonymous with percolation in connoting the rate of water movement through the soil.

Three basic soil drainage rate classifications for the study were designated: slow, moderate, and rapid. During the site selection process these categories connoted relative drainage characteristics as opposed to denoting measured drainage rates.

Relocation of the study area and difficulty in locating acceptable sites delayed the sampling work. Percolation and infiltration measurements to ascertain actual drainage rates at each sample site were delayed until the data collection process began.

Sample Sites

Selection of sample sites was based primarily on three land type classes of the U.S. Forest Service Land Type System (Appendix 1). Land type designations in the 300 series (Continental

Glaciation) predominate in the area selected for study. The land types in this series resulted from the advance and retreat (and associated scouring and filling) of lobes of the Cordilleran ice sheet (Johns 1970).

The land type system is based on several soil and topographic features other than drainage, but relative drainage characteristics are associated with each type designation. Consultation with Forest Service personnel resulted in the selection of land types 351, 352, and 355 as best approximating slow, moderate and rapid soil drainage rates, respectively.

The 351 type is characterized by deep glacial till overlain by a volcanic ash (loess) deposit. A compacted condition immediately below the loess-till interface restricts drainage. Land type 352 also consists of deep glacial till overlain by a volcanic ash deposit, but no significant compaction is noticeable. Neither of these two land types is subject to bedrock control. The type designation 355 represents moderately shallow glacial till deposits with a volcanic ash cap. Bedrock control is readily evident. On some of the sites selected, the shallow till was not present and the loess was interfaced with fractured bedrock.

The volcanic ash soils on the sample sites were assumed to have been formed in similar deposits of tephra from the eruptions of Mount Mazama. The small study area and comparable site characteristics support this assumption.

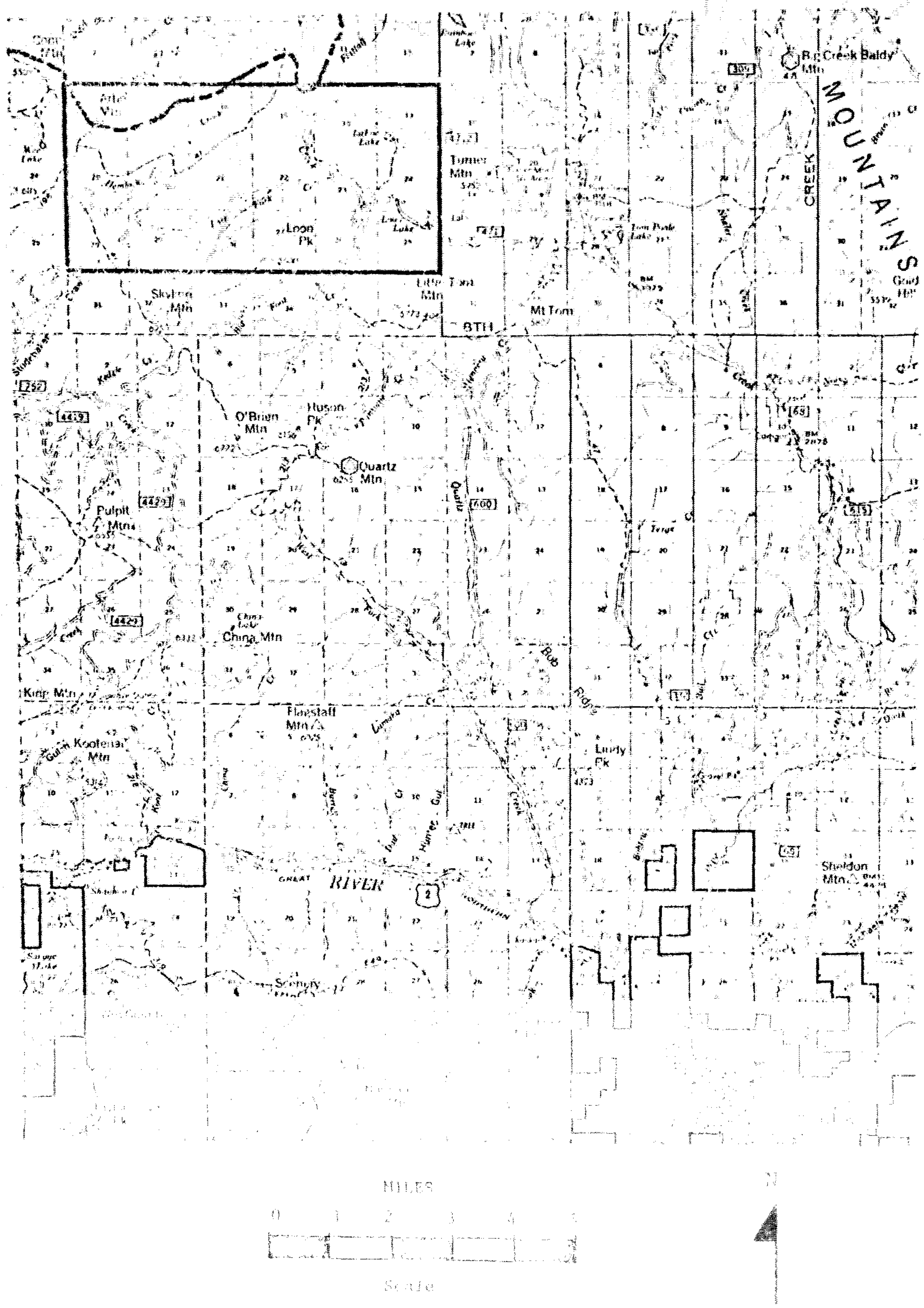
The bedrock in the study area is part of the Wallace Formation and consists primarily of calcareous or dolomitic argillite and shale (Johns 1970).

Criteria used in selecting sample sites were elevation, aspect, slope, precipitation, depth of andic material, habitat type and stocking. A summary of the criteria data for the sites selected is in Appendix 2. The presence of one species of commercial importance in sufficient abundance to allow productivity sampling was required. Age and size uniformity of the individual trees of this species were desired.

An elevation of 1,311 m $\pm$ 122 m was chosen as acceptable. Variation in aspect from NE to NW, slope from 30% to 50%, and precipitation from 86-118 cm was allowable. Depth of the andic soil was restricted to 17-35 cm. The habitat types desired, which varied little on sites meeting the other criteria, were Hemlock-Clintonia (TSHE/CLUN) or Western Redcedar-Clintonia (THPL/CLUN) (Pfister *et al.* 1977). Comparable stocking of the overstory trees was necessary, although no particular level of stocking was specified. Western larch (*Larix occidentalis* Nutt.) was the species chosen for productivity sampling. Approximately even-aged stands of second growth established after the fires of 1910 were considered usable.

Twenty sites were located which satisfied the selection criteria. The study area and site locations are marked on the maps in Figures 1 and 2. Descriptions of site locations are included

Figure 1. Location of study area in relation to Libby, Montana. (From U.S. Forest Service, Kootenai National Forest map, 1970).



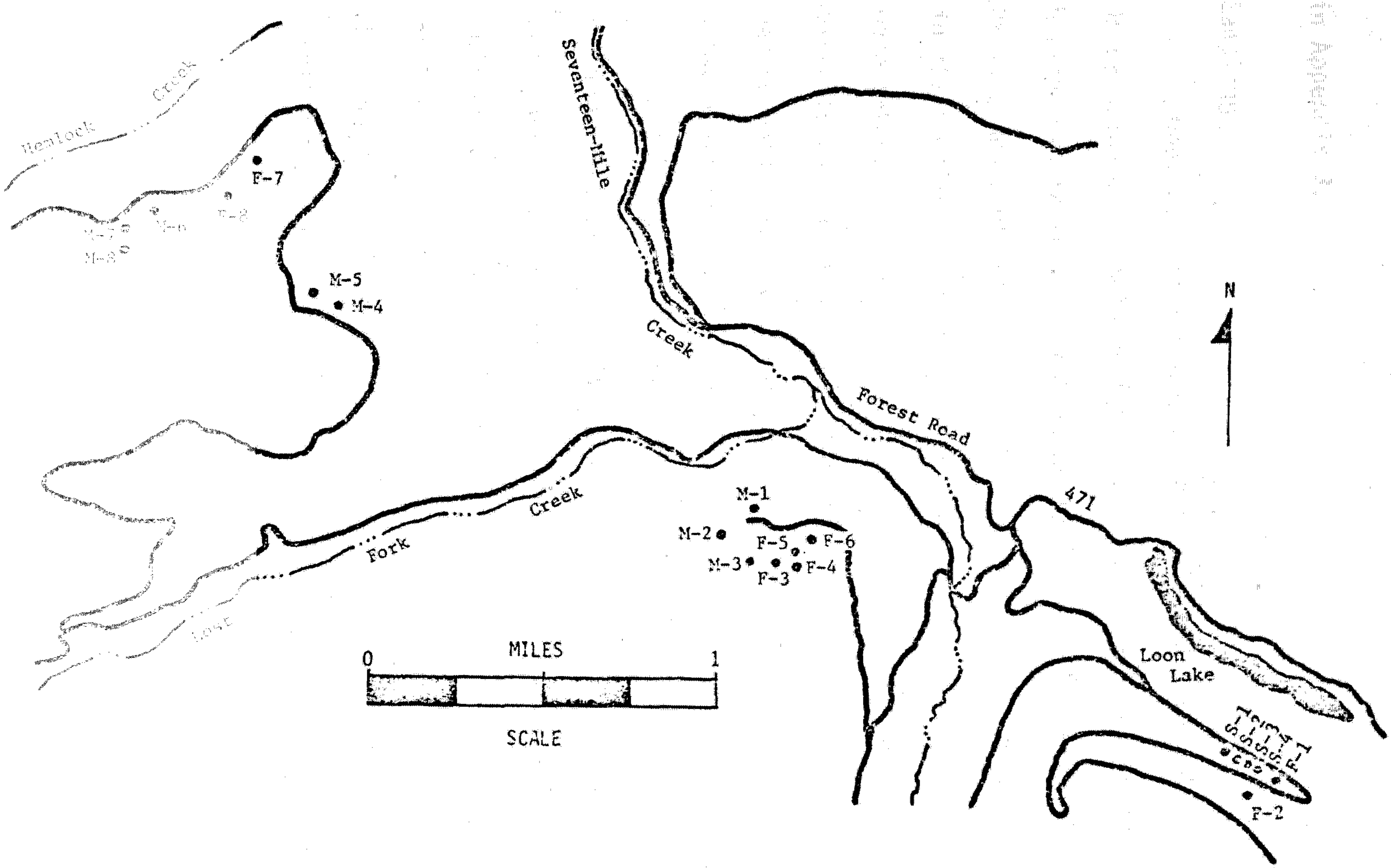


Figure 2. Enlargement of study area with sample site locations marked (From U.S. Forest Service, Kootenai National Forest Land Type map).

in Appendix 3.

Sampling

One soil pit was dug on each selected site. A soil profile description was completed for each pit, and a sample from each horizon was taken for chemical analysis (Soil Survey Staff 1975). Profile descriptions are included in Appendix 4. Rooting depth in the profile was noted, but no quantitative or taxonomic data were taken. Coarse fragment (>2mm) percentage of soil volume was visually estimated for each horizon. Samples for bulk density determination were taken immediately above and below the andic-subsoil interface.

Three sample points for infiltration and percolation rate determination were established at each site. Infiltration tests were made on the mineral soil surface using a double ring infiltrometer. The rings were pushed into the soil to a depth of at least 2.54 cm and water poured into both to a depth of 5.1 cm. The time for 2.54 cm of water to infiltrate the soil was recorded. Presoaking of the sites was not done because of time limitations.

Holes were dug at each of these sample points to expose the surface of the subsoil. The quantity and size of coarse fragments in the subsoil of these sites made the use of a steel ring for percolation tests impractical. Percolation tests were conducted by excavating a 5.1 cm diameter hole in the surface to a depth of 5.1 cm. This hole was presoaked for one hour, after which a determination of the time required for 2.54 cm of water to percolate into the soil was made. Exact dimensions of the holes were hard to duplicate owing to the excessive number of coarse fragments present. The results of these tests can be used for comparative purposes in this study, but should not be extrapolated for use in other areas. Data from the percolation tests indicated some overlap in calculated drainage rate using the original land type classification grouping.

On the basis of land type classification, four sites were considered to have slow, eight to have moderate, and eight to have rapid subsurface drainage rates. Data from the percolation tests indicated some overlap in calculated drainage rate using the original land type classification grouping.

Table 1 contains the land type and percolation rate associated with each sample site. Heterogeneity of percolation rates among the sites in the same land type indicated a need for regrouping of the sites by drainage before statistical testing.

One method of site grouping by drainage characteristics (Table 1, Drainage Rate Grouping A) was based on permeability class designations (U.S.D.A. Soil Conservation Service 1974). Very slow to moderate classes (less than 5.1 cm/hour) were designated slow drainage, the moderately rapid class (5.1-15.2 cm/hour) was designated moderate, and the rapid and very rapid classes (greater than 15.2 cm/hour) were considered rapid. The sorting of sites by this method resulted in more uniform sample sizes than

Table 1. Grouping of sample sites on the basis of land type designation and subsoil drainage rate.

			DRAINAGE RATE GROUPINGS					
			A. Percolation Rates			B. Assigned Rates		
Sample Site	Land Type	Measured Percolation Rate (cm/hr)	0-5.1 cm/hr	5.1-15.2 cm/hr	>15.2 cm/hr	0-2.54 cm/hr	2.54-25.4 cm/hr	>25.4 cm/hr
S-1	351	1.68	X			X		
S-2	351	1.80	X			X		
S-3	351	2.26	X			X		
S-4	351	2.51	X			X		
M-1	352	3.2	X				X	
M-2	352	13.2		X			X	
M-3	352	7.6		X			X	
M-4	352	6.9		X			X	
M-5	352	6.4		X			X	
M-6	352	5.6		X			X	
M-7	352	5.1	X				X	
M-8	352	7.9		X			X	
F-1	355	16.3			X		X	
F-2	355	9.4		X			X	
F-3	355	24.9			X		X	
F-4	355	152			X			X
F-5	355	127			X			X
F-6	355	180			X			X
F-7	355	17.3			X		X	
F-8	355	152			X			X

the land type grouping. Mixing of the glacial till subsoil types, and the respective physical characteristics associated with each, also occurred. Timber productivity has been shown to be related to soil physical characteristics (Copeland 1958, Cox *et al.* 1956, Carlson 1964, Coile 1948, Schlots *et al.* 1956). For this reason the sites were further regrouped by a drainage system that more closely approximated sorting by physical characteristics of the subsoil.

The second system of drainage grouping was based upon arbitrarily assigned drainage rates (Table 1, Drainage Rate Grouping B). Slow drainage was designated to be less than 2.54 cm/hour; moderate drainage, 2.54-25.4 cm/hour; and rapid, greater than 25.4 cm/hour. Although not a recognized system of drainage classification, this grouping of the sites corresponded closely to the natural breaks observed in drainage rate.

Seven western larch trees in the immediate vicinity of the soil pit were selected as site trees for productivity determination. Comparable diameter at breast height (d.b.h.), age, height, and dominance class were the criteria used in selecting site trees. Breast height is considered to be at 1.37 m.

Height for each tree was determined using a clinometer. Diameter (d.b.h. from ground level on the uphill side of the tree) was measured using a steel diameter tape. An increment core was taken on the uphill side of each tree at a height of 1.37 m.

Age at d.b.h., thickness of sapwood, number of growth rings in the sapwood, and the number of growth rings in the inner and outer 2.54 cm of each core were determined and recorded. Dominance class for each tree was assigned by position in the canopy. Site tree data is included in Appendix 5.

Age at ground level (Appendix 5) was determined from an increment core taken at ground level from one site tree at each site. A correction factor was determined which converted the age at breast height to age at ground level.

Stocking was estimated by counting the number of trees (d.b.h. greater than 10.16 cm) in a 9.14 m square and converting to stems/hectare. The soil pit was used as the center of the square. Figures for stocking (Appendix 6) derived in this manner are for use only as comparisons in this study and should not be extrapolated to other areas.

Dwarf mistletoe (*Arceuthobium* spp.) has been shown to have a significant effect on the growth rate of western larch trees in western Montana (Pierce 1960). Graham (1959), in a survey of the Kootenai National Forest, found varying levels of infection throughout the forest. Care was taken in this study to select site trees exhibiting no obvious visible evidence of dwarf mistletoe infection.

Moisture stress measurements were planned for mid-August when stress differences would be pronounced. Tests were conducted using a pressure bomb (Ritchie and Hinckley 1975) on western larch in the late evening. At least seven tests per site were to be completed within a three-to-five-day period. Rain, beginning on the second day of testing, changed the moisture status of the soil and relieved the stress on the trees. Sampling was halted at this time. A total of 102 moisture stress tests, rather than the projected minimum of 140, were completed. Data from the moisture stress tests is included in Appendix 7.

Soil moisture samples were to be taken at each site for comparison between the stress in the western larch and the moisture status of the soils. The rain made the soil moisture sampling meaningless at the time of moisture stress tests, and later sampling would have been inapplicable.

A pressure bomb was kept in Libby on the chance that the sites would begin to dry again and further moisture stress measurements could be made. Precipitation continued intermittently until the end of the field season, making further testing futile.

Xylem sap samples were taken on several sites during the early morning hours. Because trees are under least moisture stress just before dawn (Ritchie and Hinckley 1975, Running 1980), sap was easiest to collect at this time. One milliliter samples were collected utilizing a pressure bomb. Nitrogen gas was used to pressurize the bomb (maximum 1.02×10^5 g/cm^2) and force xylem sap from the cut ends of the branches. Tygon tubing placed over the cut end of the branch collected the exuded sap. The sample was measured by piercing the tubing with a clean hypodermic needle and drawing one milliliter of the sap into a syringe.

Sample Handling

Soil samples for chemical analysis were placed in plastic-lined cardboard specimen containers and stored in a cool environment. Soil moisture and bulk density samples were stored in airtight metal containers and kept cool.

Increment cores were placed in plastic soda straws and processed as soon as possible.

Xylem sap samples were brought to 25 ml using 0.12 mN hydrochloric acid (HCl), and kept on ice until transported to the laboratory. The samples were kept refrigerated until analyzed.

Laboratory Analysis

Measurement for pH was made immediately after sampling. Soil-distilled water saturated paste was measured on a HACH digital pH meter (Model 18800-10).

Soil bulk densities were determined by the saran-clod method (Black 1965, American Association of State Highway and Transportation Officials 1978) as adapted by the Kootenai National Forest. Moisture content of the samples was determined gravimetrically. Correction for moisture and coarse fragment (>2mm) content was made. Soil bulk densities for the sample sites are included in Appendix 8.

Representative samples of the upper two subsoil horizons were selected from nine sample sites. Particle size distribution was determined by the hydrometer method (Black 1965). Results of the analyses are presented in Appendix 9.

Nitrate measurements were made on a soil-distilled water saturated paste upon return to the laboratory. A nitrate electrode on an Orion Specific Ion Analyzer was used. The storage time involved before these measurements were made ranged from 3-6 weeks. Nitrate content determined for these samples is suspect as changes in concentration of nitrate occur over time and with air drying of the soil (Black 1965).

After measurement for nitrate, all soil samples were oven dried for 24 hours at 70^{o}C. Samples were then passed through a #10 (2 mm) sieve and analyzed chemically.

Extractable ion concentrations (1N NH_4OA_c) of calcium, copper, iron, potassium, magnesium, manganese, sodium, and zinc were determined by atomic absorption spectrophotometry using the Techtron AA-5 (Techtron 1974). Total nitrogen was determined by the modified microkjedahl procedure (Black 1965) on a Kjeltec System I, and extractable PO_4^{-3} by 1N NH_4F extraction and colorimetry (Black 1965).

Original soil chemical analysis and nitrate data are included in Appendix 10.

The HCl - xylem sap solution was analyzed directly by atomic absorption spectrophotometry (Techtron 1974) for calcium, copper, iron, potassium, magnesium, manganese, sodium, and zinc. Total nitrogen was determined for the solution using a modified microKjeldahl procedure (Black 1965) on a Kjeltec System I, and PO_4^{-3} by colorimetry (Black 1965). Xylem sap analysis data are included in Appendix 11.

Statistical Analysis

Student's t-tests were performed on soil and sample tree data obtained by laboratory analysis and field measurement. Testing was designed to detect only significant differences occurring between means associated with the drainage classes or land type classes within a specific drainage or land type classification grouping (Table 1). Although statistical testing was conducted within the three classification groupings, no attempt was made to compare data statistically among the groupings. Site F-4 was omitted from the statistical analyses, because the ash soil interfaced with bedrock on the site. No subsoil layer was available for sampling.

Sample means were determined for the mean concentrations (micrograms per gram) or total availabilities (milliequivalents or kilograms per unit area) of the andic and subsoil layers of the soil profiles. The summation technique was used to facilitate the t-test comparisons among layers (Brown and Loewenstein 1978).

Reference to the term, layer, includes all the soil horizons comprising that layer in the solum. For example, an andic layer may consist of A2, B21, and B22 horizons. An expression of the availability of a soil nutrient for a specific site is understood to represent the quantity available in a soil volume having a surface area of one square meter or one hectare, and a thickness corresponding to the total thickness of the andic or subsoil layer of the soil profile at that site.

Analysis of the soil nutrient data involved comparisons of means among the andic and subsoil layers of the various drainage and land type classes within each classification system. Comparisons were also made between the andic and subsoil layers within each class.

The comparison of soil nutrient concentrations was based on the microgram per gram (μg/g) composition of the eight individual cations, the sum of the eight cations, and phosphate. Nitrate concentrations in milligrams per liter (ppm) were also compared. Expression of nutrient content in terms of concentration provides a knowledge of the amount of a given soil nutrient to be expected per unit mass of soil and in relation to the other nutrients present.

Soil nutrient content, expressed in terms of quantity available per unit area of each individual cation, the sum of the eight cations, phosphate , and total nitrogen were compared. Available quantity was expressed in two ways. First, the milli-equivalent (meq) per square meter (per thickness of the respective andic or subsoil layer) quantities were compared. Bulk density determinations for the andic and subsurface horizons at the interface in each soil profile were extrapolated to all horizons in each respective layer. No correction was made for coarse fragment volume of the various horizons. This method of expressing nutrient availability gives an indication of the quantity of each nutrient present in a volume of soil composed solely of material less than 2 mm in size. These quantities can be compared directly to the nutrient availabilities in other soils. Calculations involved in the meq determinations are illustrated in Appendix 12.

The second expression of nutrient availability was as kilograms per hectare (per thickness of the respective andic or subsoil layer). Bulk densities of the horizons at the andic-subsoil interface were extrapolated to the other horizons of their layers. Soil layer volumes were corrected for the percentage of coarse fragments (>2mm) present. The expression of nutrient content in this manner allows comparison of the actual field availabilities of the eight individual cations, the sum of the eight cations, phosphate, and total nitrogen to field availabilities of nutrients in other soils.

Means for the number of growth rings in the innermost and outermost 2.54 cm of growth at d.b.h. for the sample trees were compared for drainage classes and land type. The sapwood area/

basal area ratio and site index[1] were calculated for each sample tree.

Means for the ratios and site indices in each drainage and land type category were compared within classification systems. Calculations used for the determination of sapwood area/basal area ratio are included in Appendix 12. Data for the sample trees are in Appendix 5.

Xylem extract and moisture stress data were grouped by drainage classifications and land type designation. The sample means for ion content in the xylem extract (milligrams per liter) and the pressure required to extract xylem sap from a branch (megaPascals) were compared on the basis of drainage and land type class within classification systems.

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[1] Site index curves for western larch were obtained from the Forest Science Laboratory, U.S.D.A. Forest Service, Missoula, Mont. Curves were developed from unpublished research data using a 50-year base (Appendix 8).

RESULTS AND DISCUSSION

Establishment of drainage class was initially done on the basis of the U.S. Forest Serive land typing system. The assumption was that soils mapped as meeting the criteria for the same land type designation would exhibit approximately the same subsurface drainage characteristics. Percolation testing at the time of sampling at each site proved this expectation erroneous in some cases. For this reason the sites were regrouped on the basis of the percolation tests. The original land type distribution, the percolation distribution, and the criteria used for drainage grouping are displayed in Table 1.

The results of soil nutrient comparisons for the three classifications of sample sites by drainage and land type are presented in Tables 2 through 13. Comparison results for the productivity and growth data appear in Tables 14 through 17. The three sets of comparisons that were made on the data were performed to assure that signficant differences would not be attributed to drainage if they were better explained by factors more closely related to land type.

Soil Analysis

The volcanic ash soil on site F-4 interfaced with bedrock of the Wallace formation directly, with pockets of mixed B3 material located in fractured areas of the bedrock. Because the site contained almost no developed subsoil, it was excluded from the t-test comparisons for soil nutrient content and concentration in all grouping schemes.

Surface A2 horizons have developed in some of the volcanic ash soils sampled, primarily in those of the 352 and 355 land types. An A2 horizon is noted in the profile description of the S-2 site on land type 351, but it was too poorly developed to permit the collection of acceptably representative samples.

The lack of A2 horizon development in the andic soils overlying slowly drained subsoils (the compacted till of land type 351) and its presence to varying extent on soils subject to more rapid subsurface drainage (the deep loose till of the 352 type or the shallow till and bedrock of the 355 class) appeared to indicate that differential leaching rates were occurring in the ash soils in relation to subsoil drainage. The lack of A2 development suggested less ion transport as a result of the slower drainage.

Although the profiles of some soils sampled did not include visibly developed A2 horizons in the volcanic ash layers, the original soil nutrient data (Appendix 10) indicated that some chemical depletion had occurred in the surface horizons of these profiles. The development process had not yet progressed to the point at which a visible A2 horizon was present. Significantly different leaching rates would not be expected in ash soils receiving approximately the same amounts of precipitation.

Some concern was expressed as to whether the leached condition of the volcanic ash A2 horizons might alter otherwise significant relationships within the ash soil. Separate t-test analyses were performed excluding A2 horizon data. The results were so nearly identical to those of andic soil analyses in which the A2 data were included that no further effort was made to compensate for the presence of the A2 horizons. The apparent lack of effect of the A2 horizon component on the nutrient comparisons for the andic soil indicated failure of the leached nutrients to move beyond the volcanic ash layer.

The amount of leaching which had occurred on the sites was a result of the movement of water through the andic layer and into the subsoil. Relatively low precipitation rates, the high water holding capacity inherent in andic soils, and the short time since deposition of the ash material may have combined to prevent the development of more prominent A2 horizonation.

An additional factor which must be considered is that the bulk of the annual precipitation on all sites in the study area is received in the form of snow. The large amount of moisture necessary to leach nutrients from the andic layer of the soil into the subsoil may only be present for a short time with spring snow melt. A single rapid flush resulting from the melting of the snow cover may be insufficient to completely remove a significant amount of nutrients from an ash layer of the thickness sampled.

The strongly acid nature of the soil horizons (Appendix 10) may also be limiting cation movement through the soil. Acid conditions tend to restrict respiration and nitrification as well as other processes responsible for production of various anions. The presence of anions in the soil solution is the major factor determining the quantity and rate of cation transport with water movement in the soil (McColl and Cole 1968).

The site distribution for the drainage classification and land type groupings is presented in Table 1.

Particle size analysis of the subsoils on several sites (Appendix 9) indicated that, although physically different in drainage rates and thickness, the soil contained similar percentages of sand, silt, and clay. Sand percentages (20-30%) were somewhat lower, and those of clay (25-37%) somewhat higher on slowly drained sites than on moderately or rapidly drained sites (25-48% for sand, 13-21% for clay). Variation in the sand and clay percentages was judged too small to indicate the presence of appreciably different parent materials in the subsoil.

Comparisons of the soil nutrient data means, with the exception of those relating to the nitrate, total nitrogen, and total cation components, were based upon ion concentrations or availabilities (Appendix 14). Ion concentrations were expressed in micrograms per gram of soil (<2mm size fraction). Ion availabilities were expressed, in either milliequivalents per square meter (ignoring coarse fragment content) or kilograms per hectare (correcting for coarse fragment content), for the entire andic or subsoil layer concerned. The nitrate component of the soil was reported as parts per million for inclusion in the nutrient concentration data (Appendix 14). For inclusion in the availability per square meter data (Appendix 14) the measured nitrate parts per million were weighted by the relative horizon thicknesses in each soil layer. Nitrate availability was not calculated for inclusion in the availability per hectare data. The total nitrogen component of the soil was included only with the availability per hectare data (Appendix 14) and reported as kilograms per hectare. The sum of (total) cations component was expressed only in milliequivalents per square meter for inclusion with the availability per square meter data (Appendix 14).

Potassium occurs in both available and complexed forms in the soil. Levels of total potassium in the soil were not indicated by the 1N NH_4OAc extraction. Only the potassium assumed to be readily available to plants can be measured by this extraction process. The available (extractable) potassium levels were those compared and discussed for the various groupings of sample sites.

The means and standard deviations of the soil nutrient concentrations and availabilities appear in Appendix 15.

Drainage classification A (Slow, 0-5.1 cm/hr; Moderate, 5.1-15.2 cm/hr; Rapid, 15.2 cm/hr)

Nutrient Concentration (Micrograms/gram). Table 2 presents the results of t-test comparisons among means of the soil nutrient concentrations.

Four significant differences were noted among the andic layers (Table 2). Both slowly and moderately drained soils had higher concentrations of sodium and lower concentrations of iron than soils on rapidly drained sites. The sodium differences suggested less leaching of the ash layer in the soils having slow or moderate drainage, which agreed with the lack of a visual A2.

Subsoil variation was more common (Table 2). Slowly drained soils contained greater concentrations of magnesium and manganese than those with moderate drainage. Concentrations of copper, manganese, sodium, and zinc were greater on slowly drained than on moderately drained sites. Comparison of moderately and rapidly drained soils revealed significantly higher levels of copper, sodium, and zinc on the soils having moderate drainage.

The numerous significant differences among the nutrient concentrations in the subsoils of the sample sites, as compared to the lack of differences in the volcanic ash layers, indicated support for the hypothesis concerning fertility of soils having a

Table 2. Results of soil nutrient concentration (micrograms/gram) comparisons for Kootenai National Forest sample sites grouped by drainage classification A (Student's t-test).

	-----------------				Micrograms/Gram		-----------		PPM
Comparison	Ca	Cu	Fe	K	Mg	Mn	Na	Zn	PO_4	NO_3
<u>Andic</u>										
Slow to Moderate										
Slow to Rapid			R				S			
Moderate to Rapid			R				M			
<u>Subsoil</u>										
Slow to Moderate					S	S				
Slow to Rapid		S				S	S	S		
Moderate to Rapid		M					M	M		
<u>Drainage Class</u>										
Slow										
Andic to Subsoil		S	A	A	S	A	A		A	A
Moderate										
Andic to Subsoil		S		A		A			A	
Rapid										
Andic to Subsoil			A	A	S	A	A		A	

S, M, R, or A in the table indicates the drainage class or soil layer having a significantly higher content.

(α = .05)

Drainage Class Limits

Slow 0 - 5.1 cm/hour n=6

Moderate 5.1 - 15.2 cm/hour n=7

Rapid >15.2 cm/hour n=6

volcanic ash layer. The lack of differences in the nutrient levels of the andic soils suggested comparable nutrient availability and leaching rates among the drainage classes. Differences in sodium concentrations suggested that the slowly and moderately drained soils might be leaching somewhat more slowly than those having rapidly drained subsoils, but the concentrations of less soluble nutrients exhibited no supporting evidence.

The differences among nutrient concentrations in the subsoil were more conclusive. Concentrations were seen to vary among drainage classes with no evidence of corresponding illuviation from the andic soil layer. The variation noted might be the result of the physical variation in parent material of the subsoil or of differential leaching of the subsoil materials with changes in drainage rate.

Parent material of the subsoil was glacial till remaining from the last period of continental glaciation (Johns 1970). Inherent variability is expected in soils derived from glacial till, but grouping of sites by drainage class, and comparing only the means of the nutrient concentrations should have served to mask minor heterogeneity within drainage classes. The physical aspects of the parent material also had effects on the nutrient concentrations present in the subsoil.

The differences in moisture regime, depth to bedrock, weathering rate, and other factors associated with the three glacial till deposits would cause possible differences in the nutrient concentrations between drainage classes. Some mixing of till types occurred with the grouping of sites by drainage. The mixing, while eliminating some of the heterogeneity among classes, made interpretation of noted differences in subsoil nutrient concentration more complicated.

If the differences among nutrient concentration caused by physical differences in the glacial till parent materials were discounted, the results of the comparisons indicated that the nutrient concentrations in the subsoil were related to drainage rate. Soil nutrients leaching from the volcanic ash soil were eluviating at a relatively uniform rate. With the exception of minor movement of water downslope, especially on the sites having the compacted till interfacing with the volcanic ash, the nutrients in the soil solution were carried into the glacial till subsoils. The rate of soil solution movement through the subsoil appeared to affect the concentrations of soil nutrients retained. The slower the soil drainage, the higher the nutrient concentration present. The presence of an increased clay content only in the second horizon of the buried soil on the slowly drained sites supported this indication (Appendix 9).

Comparison of the volcanic ash layer to the buried soil (Table 2) on slowly drained sites disclosed lower concentrations of copper and magnesium, and higher concentrations of iron, potassium, manganese, sodium, phosphate, and nitrate in the ash. Moderately drained subsoil contained higher concentrations of copper than the ash soil. Potassium, manganese, and phosphate concentrations were higher in the ash of both rapidly and moderately drained soils than in the subsoil layers. Magnesium concentration was higher, and iron and sodium concentrations lower, in the rapidly drained subsoil than in the andic layer.

The higher concentrations of iron and phosphate in the andic soil as compared to the subsoil was expected. Iron is normally found in abundance in soils derived from volcanic ash. According to Jones *et al.* (1979) phosphorus is sorbed in greater quantities by andic soils than by soils derived from glacial sediment. Brown (1977) notes that the levels of adsorbed phosphorus are in equilibrium with solution phosphorus. Powers and Wilcox (1964) report large amounts of iron sesquioxides in andic soil horizons derived from Mount Mazama ash. These sesquioxides supply available iron and contribute to the sorption of solution phosphorus. Manganese concentration would be expected to be higher in a subsoil derived from glacial till deposits overlying calcareous or dolomitic argillites and shale than in an andic soil. The higher potassium concentration in the andic soil layer of all three drainage classes, the higher levels of sodium and nitrate in the slowly drained ash, and the higher sodium in the rapidly drained andic layer indicated that excessive leaching of the ash soil had not occurred. Being soluble, these ions would be the first to be eluviated from the andic layer.

Nutrient Availability per Square Meter (Drainage Classification A). The results of the comparisons of means for soil nutrient content expressed as milliequivalents per square meter are tabulated in Table 3.

In the volcanic ash layers the magnesium and phosphate contents were significantly higher in slowly drained soils than in those on moderately drained sites (Table 3). Ash soils on sites having rapid subsurface drainage contained less sodium than ash layers over moderately drained subsoil. Rapidly drained sites contained a higher level of iron than moderately drained sites, and a higher potassium content than either slow or moderately drained soils. The sodium relationship between the andic layers of the rapidly and moderately drained soils appeared to indicate greater leaching on the rapidly drained sites.

The subsoil layers exhibited a somewhat larger number of significant differences in nutrient content (Table 3). Potassium, magnesium, and manganese content was higher in slowly drained soils than in those on moderately drained sites. The slowly drained subsoils contained significantly larger amounts of copper, iron, magnesium, manganese, sodium, and zinc as well as a larger total

Table 3. Results of soil nutrient content (milliequivalents/square meter) comparisons for Kootenai National Forest sample sites grouped by drainage classification A (Student's t-test).

	------------Milliequivalents/Square Meter							----------		Weighted PPM	
Comparison	Ca	Cu	Fe	K	Mg	Mn	Na	Zn	Total Cations	PO_4	NO_3
Andic											
Slow to Moderate					S					S	
Slow to Rapid				R							
Moderate to Rapid			R	R			M				
Subsoil											
Slow to Moderate				S	S	S					
Slow to Rapid		S	S		S	S	S	S	S		
Moderate to Rapid		M					M	M			
Drainage Class											
Slow											
Andic to Subsoil	S	S	S	S	S	S	S	S	S	A	A
Moderate											
Andic to Subsoil	S	S	S		S	A	S	S	S		
Rapid											
Andic to Subsoil	S	S			S	A	S	S	S	A	

S, M, R, or A in the table indicates the drainage class or soil layer having a significantly higher content.

(α = .05)

Drainage Class Limits

Slow 0 - 5.1 cm/hour n=6

Moderate 5.1 - 15.2 cm/hour n=7

Rapid >15.2 cm/hour n=6

cation content than those with rapid drainage. Copper, sodium, and zinc availabilities were lower on rapidly drained sites than on those with moderate drainage.

The higher nutrient availabilities in the slowly drained soils as compared to the sites having moderate and rapid drainage, and in the moderately drained soils as compared to the rapidly drained sites, were due in part to the increasing depth and bulk density of the glacial till soils with decreasing drainage rate. The differential accumulation (or leaching) of nutrients related to variation in subsoil drainage, as suggested by the nutrient concentration comparisons, would also have contributed.

Comparison of the nutrient contents of the volcanic ash horizon and the buried soil (Table 3) on slow sites indicated greater amounts of phosphate and nitrate in the ash, with all other elements occurring in larger quantities in the subsoil. On moderately drained sites the ash horizon was higher in manganese and lower in calcium, copper, iron, magnesium, sodium, zinc, and total cation contents. The rapidly drained subsoil contained greater quantities of calcium, copper, magnesium, sodium, and zinc than the andic layer, but signficantly less manganese and phosphate. Total cation content was also higher in the subsoil of the rapidly drained sites.

The apparent tendency for significantly greater nutrient contents to be found in the subsoil of all drainage classes, as compared to their respective andic soil layers, was presumably linked to the greater mass of soil present in the subsoil layers. The continued greater availability of phosphate in the andic as opposed to the buried soils on the slowly and rapidly drained sites was further evidence of the ability of volcanic ash soils to fix phosphorus. Nitrate availability would be expected to be significantly higher in ash soils than in the subsoils because the requirements for aeration, moisture, and temperature demanded by the nitrobacteria are better met in soils lying near the surface and having greater moisture holding capacities and low bulk densities. Nitrates are readily leached from soils, and the lack of significantly high available quantities in the andic soils of rapidly and moderately drained sites indicated the possibility of differential leaching of the ash layers among the drainage classes.

Nutrient Availability per Hectare (Drainage Classification A). Comparison of the means for kilogram per hectare content of the three drainage rate classes is presented in Table 4.

Zinc content of volcanic ash layers on moderately drained sites was significantly higher than on either slowly or rapidly drained sites (Table 4). Moderately drained andic soils contained more sodium than soils with rapid drainage, again indicating a possible tendency toward more rapid leaching with increased drainage rate. Andic soils on rapidly drained sites contained less phosphate than those on slowly drained sites, indicating possible leaching losses.

Table 4. Results of soil nutrient content (kilograms/hectare) comparisons for Kootenai National Forest sample sites grouped by drainage classification A (Student's t-test).

	------------Kilograms/Hectare------------									
Comparison	Ca	Cu	Fe	K	Mg	Mn	Na	Zn	PO_4	Total N
Andic										
Slow to Moderate								M		
Slow to Rapid									S	
Moderate to Rapid							M	M		
Subsoil										
Slow to Moderate				S	S	S				S
Slow to Rapid	S	S		S	S	S	S	S		S
Moderate to Rapid		M	M					M		
Drainage Class										
Slow										
Andic to Subsoil	S	S			S		S		A	A
Moderate										
Andic to Subsoil		S		A		A			A	A
Rapid										
Andic to Subsoil			A	A		A		A	A	A

S, M, R, or A in the table indicates the drainage class or soil layer having a significantly higher content.

(α = .05)

Drainage Class Limits

Slow 0 - 5.1 cm/hour n=6

Moderate 5.1 - 15.2 cm/hour n=7

Rapid >15.2 cm/hour n=6

The quantities of potassium, magnesium, manganese, and total nitrogen in the subsoil of slowly drained sites were greater than for soil with either of the other drainage rates (Table 4). Calcium, copper, sodium, and zinc quantities were greater on sites having slow drainage than on those draining rapidly. Rapidly drained soils were lower in copper, iron, and zinc content than soils having moderate drainage.

Variation in the results of soil nutrient availability comparisons between Table 3 and 4 was evident. This variation was cuased by the correction for the estimated coarse fragment (>2mm) percentage in the volume of each soil horizon for the data expressed in kilograms per hectare. Expression of the nutrient quantities in this manner gave a more meaningful indication of the actual quantities of soil nutrients available for vegetative growth than in availability expressions ignoring coarse fragments. The pronounced variability observed in the results of comparisons among andic soils (Tables 3 and 4) was due to the relatively wide variation in coarse fragment percentages (Appendix 10) in the thin volcanic ash horizons. Less variability in coarse fragment percentages and greater overall horizon thicknesses in the subsoil accounted for the much more limited variation in the subsoil comparison results between Tables 3 and 4. The estimates of coarse fragment content (>2mm) of the soil (by volume percentage) were made during the soil profile description and sampling procedure.

The amounts of available phosphate and total nitrogen were higher, and those of calcium, copper, magnesium, and sodium lower, in the andic layer of slowly drained soils as compared to the subsoil on the same sites (Table 4). Moderately drained soils were lower in copper and higher in potassium, manganese, phosphate, and total nitrogen content in the volcanic ash soil. On rapidly drained sites the subsoil was significantly lower in available iron, potassium, manganese, zinc, phosphate, and total nitrogen than was the ash layer.

Correcting the nutrient quantities available in the soil for the volume of coarse fragments (>2mm) present resulted in fewer significant differences between the andic and buried soils in the different drainage classes. The higher phosphate content in the andic soils confirmed expectations. Total nitrogen quantities were also higher in the andic layers reflecting the greater quantity of organic matter and the larger number of microorganisms within the ash soil.

Drainage Classification B (Slow, 0-2.54 cm/hr; Moderate, 2.54-25.4 cm/hr; Rapid, > 25.4 cm/hr)

Nutrient Concentration (Micrograms/Gram). Table 5 contains the results obtained when the mean concentrations of the soil nutrients were compared under drainage classification B.

Table 5. Results of soil nutrient concentration (micrograms/gram) comparisons for Kootenai National Forest sample sites grouped by drainage classification B (Student's t-test).

	----------------Micrograms/Gram-----------								PPM
Comparison	Ca	Cu	Fe	K	Mg	Mn	Na	Zn	PO_4	NO_3
Andic										
Slow to Moderate									S	
Slow to Rapid										
Moderate to Rapid			R							
Subsoil										
Slow to Moderate				S	S	S			M	
Slow to Rapid					S		S	S		
Moderate to Rapid									R	
Drainage Class										
Slow										
Andic to Subsoil		S	A	A	S	A			A	A
Moderate										
Andic to Subsoil		S	A	A	S	A	A		A	A
Rapid										
Andic to Subsoil				A			A			

S, M, R, or A in the table indicates the drainage class or soil layer having a significantly higher concentration.

($\alpha = .05$)

Drainage Class Limits

Slow 0 - 2.54 cm/hour n=4

Moderate 2.54 - 25.4 cm/hour n=12

Rapid $>$ 25.4 cm/hour n=3

The volcanic ash layer of the slowly drained sites contained greater concentrations of phosphate than did sites with moderate drainage. Iron concentration was greater on sites with rapid, as opposed to moderate, drainage. Subsoil drainage had no apparent significant effects on the concentrations of the more soluble nutrients in this drainage grouping.

The concentrations of magnesium, potassium, and manganese were higher in the subsoil of slowly drained sites than in that of moderately drained sites (Table 5). Magnesium, sodium, and zinc levels were significantly lower on sites with rapid drainage rates, as compared to those with slow rates. Moderately drained soils had greater phosphate concentrations than slowly drained soils, and lower phosphate concentrations than those with rapid drainage.

The greater concentration of nutrients in the subsoil on slowly drained sites than on sites having moderate or rapid drainage rates was important. The presence of three physically different parent materials undoubtedly resulted in some significant differences in nutrient concentration, but subsoil drainage rates may have contributed to these differences also.
Nutrient concentrations in volcanic ash soils do not appear to have been strongly affected by varying rates of subsoil drainage (Tables 2 and 5). The inherently low fertility, cation exchange capacity, and moisture holding capability of the coarse glacial till subsoils may have made these subsoils susceptible to differential leaching with varying soil drainage rates. The results of subsoil nutrient

concentration comparisons (Tables 2 and 5) indicated that this could have been the case.

Andic soil on slowly drained sites contained greater concentrations of iron, potassium, manganese, phosphate, and nitrate, and lower concentrations of copper and magnesium than the subsoil on the same sites (Table 5). The buried soil on sites having moderate drainage rates was lower in potassium, iron, manganese, sodium, nitrate, and phosphate concentrations, but higher in magnesium and copper than was the ash layer. Volcanic ash soils on sites draining rapidly contained higher potassium and sodium concentrations than the underlying subsoil.

The significantly greater concentrations of sodium and nitrate in the andic soil compared to the subsoil on moderately drained sites, and the higher concentrations of sodium and nitrate in the andic layers of the rapidly and slowly drained sites, respectively, indicated that leaching on these sites was not effective in removing sodium or nitrates from the upper soil horizons. The higher potassium concentrations in the andic layer, as opposed to the subsoil, of all drainage classes confirmed the lack of nutrient movement from the volcanic ash soil to the underlying glacial till. The presence of phosphate and iron in greater concentrations in the andic material was predictable.

Nutrient Availability per Square Meter (Drainage Classification B). Displayed in Table 6 are the results of t-test comparisons of the means of milliequivalent per square meter contents of the soil nutrients.

Under this drainage classification grouping only one significant difference in content was apparent among the andic soils (Table 6). On slowly drained soils the amount of available phosphate was greater than that found in moderately drained areas. There was no apparent indication that nutrient availability in the andic soil layers was affected by subsurface drainage rate.

The subsoil on sites draining slowly contained significantly greater quantities of magnesium and manganese than moderately drained soils (Table 6). Slowly drained subsoil had higher levels of all the nutrients tested, with the exception of iron, nitrate, and phosphate, when compared to the buried soils on rapidly drained sites. Subsoils with rapid drainage contained more phosphate than those draining slowly. Total cation availability was also greater on the slowly drained sites. Significantly greater amounts of copper, potassium, and sodium were found on moderately drained sites than on those which were rapidly drained.

The tendency for greater nutrient availability to occur in subsoils having increasingly slower drainage corresponded to the indications of nutrient concentrations (Tables 2 and 5). Higher phosphate availability in the subsoil of the rapidly drained sites,

Table 6. Results of soil nutrient content (milliequivalents/square meter) comparisons for Kootenai National Forest sample sites grouped by drainage classification B (Student's t-test).

	------------Milliequivalents/Square Meter---------										Weighted PPM
Comparison	Ca	Cu	Fe	K	Mg	Mn	Na	Zn	Total Cations	PO_4	NO_3
Andic											
Slow to Moderate										S	
Slow to Rapid											
Moderate to Rapid											
Subsoil											
Slow to Moderate					S	S					
Slow to Rapid	S	S		S	S	S	S	S	S	R	
Moderate to Rapid		M		M			M				
Drainage Class											
Slow											
Andic to Subsoil	S	S	S	S	S	S	S	S	S	A	A
Moderate											
Andic to Subsoil	S	S	S		S	A	S	S	S		A
Rapid											
Andic to Subsoil				A							

S, M, R, or A in the table indicates the drainage class or soil layer having a significantly higher content.

(α = .05)

Drainage Class Limits

Slow 0 - 2.54 cm/hour n=4

Moderate 2.54 - 25.4 cm/hour n=12

Rapid >25.4 cm/hour n=3

as compared to that in soils having slow drainage, may have been a result of the tendency for volcanic ash soil to be moved downward and mixed with the thin glacial till mantle. The rapidly drained sites in this classification have a very thin veneer of glacial till over bedrock (Table 1, Appendix 1). Loose till and fractured bedrock near the volcanic ash-subsoil interface account for the very rapid drainage, and may have abetted a mixing process.

Volcanic ash soils on slowly drained sites, while containing more phosphate and nitrate, contained lesser amounts of all eight cations than the buried soil (Table 6). The total cation level was also significantly lower for the ash layer. The subsoil on sites with moderate drainage rates had greater available quantities of calcium, copper, iron, magnesium, sodium, and zinc than did the andic soil. Total cation content was higher in the subsoil as well, but manganese and nitrate were present in larger amounts in the andic layer. With the exception of the nitrate, potassium, and manganese content comparisons in the moderately drained soils, the results of the soil nutrient content comparisons for both the slowly and moderately drained sites were identical. The only significant difference evident between the andic and subsoil layers on rapidly drained sites was in potassium content, with the andic soil containing the greater amount.

The lack of significant differences between the andic and subsoil layers on the rapidly drained sites could probably be attributed to the thin subsoil present on those sites and the mixing of volcanic ash and glacial till soils at the interface.

Nutrient Availability per Hectare (Drainage Classification B). The results of the comparisons of nutrient means for the kilogram per hectare contents of soils in drainage class B are presented in Table 7.

The andic soils on slowly drained sites were poorer in available manganese and zinc than were those on moderately drained sites (Table 7). Copper was present in greater abundance on moderately drained sites than on rapidly drained ones. No indication that nutrient content in the andic soil was affected by subsoil drainage could be found.

Slowly drained subsoils contained significantly more calcium, copper, potassium, magnesium, manganese, and total nitrogen than did those on either rapidly or moderately drained sites (Table 7). Iron was available in greater quantities on sites having slow drainage than in moderately draining soils. Sites having rapid drainage rates contained less sodium and zinc than slowly drained sites, and less calcium, copper, potassium, sodium, and zinc than moderately drained sites. These results could be interpreted to support the primary hypothesis as they indicated that either a differential accumulation of nutrients from the andic layer was occurring in the subsoil, or that a differential leaching of nutrients is occurring in the subsoil, with relation to drainage rate. An inverse relationship appeared to exist between the quantity of soil nutrient available and the drainage rate of

Table 7. Results of soil nutrient content (kilograms/hectare) comparisons for Kootenai National Forest sample sites grouped by drainage classification B (Student' t-test).

	-----------Kilograms/Hectare--------------------									
Comparison	Ca	Cu	Fe	K	Mg	Mn	Na	Zn	PO_4	Total N
<u>Andic</u>										
Slow to Moderate						M		M		
Slow to Rapid										
Moderate to Rapid		M								
<u>Subsoil</u>										
Slow to Moderate	S	S	S	S	S	S				S
Slow to Rapid	S	S		S	S	S	S	S		S
Moderate to Rapid	M	M		M			M	M		
<u>Drainage Class</u>										
Slow										
Andic to Subsoil	S	S			S		S		A	A
Moderate										
Andic to Subsoil		S	A	A	S	A			A	A
Rapid										
Andic to Subsoil			A	A						

S, M, R, or A in the table indicates the drainage class or soil layer having a significantly higher content.

(α = .05)

Drainage Class Limits

Slow 0 - 2.54 cm/hour n=4

Moderate 2.54 - 25.4 cm/hour n=12

Rapid > 25.4 cm/hour n=3

of the subsoil. The small sample size and shallow subsoil of the rapidly drained sites made conclusions concerning this relationship tenuous.

Volcanic ash soils contained more calcium, copper, magnesium, and total nitrogen than did the subsoils on slowly drained sites (Table 7). On moderately drained sites the copper and magnesium contents were greater in the subsoil, but manganese, phosphate, iron, potassium, and total nitrogen were more abundant in the ash layer. Iron and potassium were present in larger quantities in volcanic ash soil than in the buried soil on sites exhibiting rapid drainage.

Correction of the quantities of soil nutrients available in the andic and glacial till soils for the percentage of coarse fragments (>2mm) present reduced the number of significant differences which appeared (Tables 6 and 7) in the volcanic ash-subsoil comparisons for each drainage class. Higher phosphate, total nitrogen, and iron in the andic, and higher calcium and magnesium in the subsoil, matched expectations. Greater availability of potassium occurred in the andic layers, as compared to the subsoil, of moderate and rapid drainage classes. No significant differences noted in the results of the comparisons of andic and subsoil layers in slowly drained soils suggested differential leaching of the ash layer with subsoil drainage rate. The relationships indicated that the ash soils on the two more rapidly drained sites were not being leached at a faster rate than the ash on the more slowly drained soil. Drainage rate of the subsoil, as expected, did not appear to be affecting the nutrient availabilities in the volcanic ash soil.

Land Type Classification

Briefly, the land type designations used in this study were:

351 volcanic ash soil over deep, compacted glacial till; associated with slow drainage rates in this study.

352 volcanic ash soil over deep glacial till; associated with moderate drainage in this study.

355 volcanic ash soil over shallow glacial till, exhibiting bedrock control; associated with rapid drainage in this study.

Nutrient Concentration (Micrograms/Gram). Comparison of the means of microgram per gram elemental concentrations found in the andic and subsoil layers of the sample soils produced the results in Table 8.

Andic soils on sites of the 352 land type contained significatnly higher concentrations of sodium than those on the 355 land type (Table 8). Manganese concentration was also higher on the 352 than on the 351 type. Iron concentration was greater in the ash soil of 355 land types than in that of 352 types. Magnesium and phosphate were in greater concentration in the ash of 351 soils, as compared to 352 sites. Zinc was in greater concentrations in andic layers on 351 sites, as compared to 355 sites.

Table 8. Results of soil nutrient concentration (micrograms/gram) comparisons for Kootenai National Forest sample sites grouped by land type classification (Student's t-test).

	--------------Micrograms/Gram------------								PPM
Comparison	Ca	Cu	Fe	K	Mg	Mn	Na	Zn	PO_4	NO_3
Andic										
351 to 352					351	352			351	
351 to 355								351		
352 to 355			355				352			
Subsoil										
351 to 352				351	351	351			352	
351 to 355		351			351	351	351	351		
352 to 355		352		355			352	352		
Land Type Class										
351										
Andic to Subsoil		S	A	A	S	A			A	A
352										
Andic to Subsoil		S		A	S	A	A		A	
355										
Andic to Subsoil		S	A	A	S	A	A		A	

Land type class, S, or A in the table indicates the class or soil layer having a significantly higher concentration.

(α = .05)

Land Type	Sample Size
351	n=4
352	n=8
355	n=7

The higher sodium concentration in the andic soil of type 352 when compared to the andic layer on the 355 land types indicated that possible differential leaching did occur.

The compacted till of the 351 sites contained heavier concentrations of potassium, magnesium, and manganese, and lower concentrations of phosphate, than the non-compacted till on the 352 sites (Table 8). The subsoil of sites in the 355 class contained lower levels of copper, sodium, and zinc than that of either of the other two land types, and higher levels of potassium than the 352 land type. Magnesium and manganese concentrations were higher in soils on 351 land types than in those on 355 types. These relationships, especially those regarding sodium concentrations, appeared to support the theory concerning differential leaching of the glacial till subsoils, and, thus, the hypothesis concerning andic soil fertility. In this case the differential leaching appeared related to land type.

The andic soil layer on the 351 land type contained greater concentrations of iron, potassium, manganese, phosphate, and nitrate than the underlying subsoil layer. The copper and magnesium concentrations were higher in the subsoil than in the andic layer of all three land types. Higher potassium, manganese, sodium, and phosphate concentrations occurred in the andic soil, as opposed to the substratum in both the 352 and 355 land types. Iron level was higher in the ash layer of the 355 type than in the subsoil. The results concerning iron and phosphate were expected on the basis of andic soil characteristics. Leaching of soil nutrients from the volcanic ash was not obviously linked to land type (and the associated drainage rate classes).

Nutrient Availability per Square Meter (Land Type Classification). Results of the t-test comparisons on means of the milliequivalent per square meter content of sample soil layers are presented in Table 9.

The volcanic ash soil overlying compacted glacial till in land type 351 contained significantly smaller amounts of available calcium and potassium than that overlying the shallow till of the 355 type (Table 9). Total cation content was also lower in the 351 as compared to the 355 class.

The compacted till of the 351 land type contained more magnesium and manganese than the looser till on 352 types, and more copper, manganese, sodium, and zinc than the shallow till of the 355 type (Table 9). The loose till on 352 sites contained significantly larger quantities of copper, sodium, and zinc than the substratum of the 355 sites.

Comparison of the subsoil nutrient content means grouped by land type produced fewer significant results than comparable comparisons based upon drainage class groupings (Tables 3, 6, and 9). The significant results that were noted did indicate that nutrient availabilities were highest in the subsoils of 351 land types and lowest in those of the 355 types. If general

Table 9. Results of soil nutrient content (milliequivalents/square meter) comparisons for Kootenai National Forest sample sites grouped by land type classification (Student's t-test).

	----------- Milliequivalents/Square Meter ----------									Weighted PPM	
Comparison	Ca	Cu	Fe	K	Mg	Mn	Na	Zn	Total Cations	PO_4	NO_3
Andic											
351 to 352											
351 to 355	355			355					355		
352 to 355											
Subsoil											
351 to 352					351	351					
351 to 355		351				351	351	351			
352 to 355		352					352	352			
Land Type Class											
351 Andic to Subsoil	S	S	S	S	S	S	S	S	S		A
352 Andic to Subsoil	S	S	S		S	A	S	S	S		
355 Andic to Subsoil	S	S			S	A			S		

Land type class, S, or A in the table indicates the class or soil layer having a significantly higher content.

($\alpha = .05$)

Land Type	Sample Size
351	n=4
352	n=8
355	n=7

drainage class designations of slow, moderate, and rapid were associated with land types 351, 352, and 355, respectively, the results conformed to those noted for subsoils in the other drainage classification site groupings.

The subsoil on 351 sites contained a greater total cation content as well as significantly larger amounts of all eight cations when compared to the volcanic ash layer (Table 9). Nitrate content of the ash layer was greater than that of the subsoil. On sites designated 352, manganese content was greater in the ash but calcium, copper, iron, magnesium, sodium, and zinc contents were greater in the subsoil. Total cation content was also greater in the subsoil. Manganese content was higher in the ash layer of the 355 land type, but available calcium, copper and magnesium amounts, as well as the amount of total available cations, were higher in the subsoil.

The majority of significantly higher soil nutrient contents were in the subsoil layers, as compared to available contents of the andic soil layers, of all three land type classes. The greater volume per square meter of the subsoil, compared to that of the volcanic ash layer, accounted for the one-sided results.

Nutrient Availability per Hectare (Land Type Classification). Table 10 presents the results of comparisons between the means of the kilogram per hectare soil nutrient contents using Student's t-tests.

No significant differences in the content of soil nutrients

Table 10. Results of soil nutrient content (kilograms/hectare) comparisons for Kootenai National Forest sample sites grouped by land type classification (Student's t-test).

Comparison	Ca	Cu	Fe	K	Mg	Mn	Na	Zn	PO_4	Total N
	-----------Kilograms/Hectare-----------									
<u>Andic</u>										
351 to 352										
351 to 355										
352 to 355										
<u>Subsoil</u>										
351 to 352						351				351
351 to 355	351	351	351		351	351	351	351		351
352 to 355		352					352	352		
<u>Land Type Class</u>										
351										
Andic to Subsoil	S	S			S					A
352										
Andic to Subsoil		S		S		A			A	A
355										
Andic to Subsoil			A	A		A		A	A	A

Land type class, S, or A in the table indicates the class or soil layer having a significantly higher content.

(α = .05)

<u>Land Type</u>	<u>Sample Size</u>
351	n=4
352	n=8
355	n=7

in andic soils were noted (Table 10). The lack of significant differences among andic soils indicated that no differential leaching of those soil layers was occurring when ranked by this classification system.

Subsoil on the 351 land type contained greater amounts of manganese and total nitrogen than was found in the subsoil of either the 352 or 355 types (Table 10). The shallow till of the 355 land type contained less calcium, copper, iron, magnesium, sodium, and zinc than the compacted till of the 351 type.

These results, while differing from those obtained using the milliequivalent per square meter comparisons (Table 9), continued to emphasize the inverse relationship between subsoil nutrient content and the drainage rates associated with the land type classes. Differences noted in the results were caused by the correction for coarse fragment (>2mm) volume in the kilogram per hectare comparisons.

The volcanic ash layer on 351 sites was poorer in clacium, copper, and magnesium than the compacted till subsoil, but contained significantly more total nitrogen (Table 10). The deep, loose till of sites on the 352 land type contained more copper and potassium, but less manganese, phosphate, and total nitrogen, than its overlying ash layer. The volcanic ash layers on 355 land types had larger available quantities of iron, potassium, manganese, zinc, phosphate, and total nitrogen than the subsoil layer.

Correction for coarse fragment (>2mm) volume in the kilogram per hectare comparisons of soil nutrients in the andic and subsoil layers of each land type caused a number of significant differences between the results observed in Table 10 and those of the milliequivalent per square meter comparisons (Table 9). Most notable were the instances in which the nutrient content of the andic soils became significantly greater than those of the underlying subsoil.

Comparison with Other Andic Soils

Table 11 contains the μg/g means of the soil nutrients by soil layer for the Kootenai National Forest sample sites of this study. Table 12 presents the microgram per gram (μg/g) concentration of various soil nutrients from western larch sites in the Libby area (Stark 1977). Sites producing good and poor growth are included.

Examination of Table 11 indicates that the volcanic ash soil was generally a more favorable medium for conifer growth than the subsoil. Iron (2 - 8 μg/g), and potassium (80 - 220 μg/g) concentrations were more favorable in the andic layer than in the subsoil. Subsoil concentrations were comparable to those in the andic layer for calcium (300 - 1500 μg/g) and copper (0.8 - 3.1 μg/g), and tended to be within favorable limits. Subsoil concentrations of iron and potassium were lower than desirable levels. Magnesium (22 - 75 μg/g) was lower in the ash soil than in the subsoil, and was also lower than desired for good conifer growth.

Table 11. Mean ion concentration (micrograms/gram), pH, and Ca/Mg ratio for andic and subsoil layers at each Kootenai National Forest sample site.

Site Code	Soil Layer	Ca	Cu	Fe	K	Mg	Mn	Na	Zn	PO_4	NO_3	pH	Ca/Mg
		Micrograms/Gram									Mg/L		
S-1	Andic	635.00	0.90	4.00	84.64	53.07	7.09	24.71	0.38	96.94	4.0	5.75	12.0
	Subsoil	878.79	1.78	3.24	55.30	159.97	4.03	17.48	0.50	5.67	2.4	5.16	5.5
S-2	Andic	950.87	1.50	4.57	170.00	57.96	3.91	28.00	0.40	55.96	4.1	5.56	16.4
	Subsoil	757.85	1.94	1.64	54.11	93.61	2.24	17.68	0.35	2.19	3.4	5.24	8.1
S-3	Andic	800.00	1.61	4.00	102.50	45.83	8.67	19.08	0.40	94.97	3.8	5.70	17.5
	Subsoil	634.82	2.60	1.48	42.86	99.50	3.41	18.79	0.37	1.47	2.1	5.21	6.4
S-4	Andic	621.79	1.50	3.57	134.14	54.43	7.57	14.43	0.36	116.54	2.3	5.30	11.4
	Subsoil	773.00	2.09	2.20	63.32	137.40	3.89	16.80	0.36	3.77	1.8	5.05	5.6
M-1	Andic	449.59	2.42	4.73	95.21	29.21	9.46	26.92	0.81	21.36	2.0	4.63	15.4
	Subsoil	665.18	3.10	2.18	31.07	45.07	3.00	13.95	0.58	2.95	2.1	4.72	14.8
M-2	Andic	809.38	1.94	4.45	111.17	42.42	9.23	24.58	0.57	27.26	2.8	5.05	19.1
	Subsoil	1091.43	2.10	4.04	39.04	34.21	2.56	19.46	0.45	2.47	2.3	5.57	31.9
M-3	Andic	405.91	1.94	3.55	106.36	22.41	10.05	23.00	0.43	11.22	2.7	4.39	18.1
	Subsoil	648.36	2.32	1.25	33.10	67.69	1.69	19.14	0.51	3.86	3.1	5.15	9.6
M-4	Andic	709.83	1.37	1.25	153.21	42.92	13.76	36.12	0.50	136.08	2.7	5.26	16.5
	Subsoil	943.28	1.77	1.00	38.31	112.83	1.45	33.21	0.45	2.82	2.3	5.40	8.4
M-5	Andic	972.86	1.19	1.33	105.36	37.14	8.39	45.00	0.35	28.96	4.5	5.46	26.2
	Subsoil	581.43	1.63	1.64	34.11	66.54	1.36	12.75	0.28	4.21	3.6	5.06	8.7
M-6	Andic	282.92	1.28	4.04	171.67	31.25	9.39	20.13	0.33	18.35	3.0	5.18	9.1
	Subsoil	234.00	1.96	1.00	22.00	24.20	0.50	12.90	0.34	21.24	2.4	4.55	9.7
M-7	Andic	585.83	0.83	3.02	154.38	52.38	10.00	22.54	0.15	56.23	3.3	4.79	11.2
	Subsoil	663.57	1.45	1.86	36.43	76.93	1.18	12.11	0.20	33.56	2.8	5.03	8.5
M-8	Andic	1310.00	1.21	4.57	181.29	42.00	9.21	18.57	0.10	23.70	3.5	5.60	31.2
	Subsoil	784.48	1.91	6.00	28.45	58.31	1.14	11.82	0.20	16.97	2.8	5.67	13.5
F-1	Andic	730.00	1.20	3.90	200.20	48.60	11.90	16.60	0.10	125.58	3.4	5.24	14.7
	Subsoil	335.53	1.37	1.00	72.89	87.53	2.18	11.61	0.10	2.94	2.0	4.50	3.8
F-2	Andic	850.00	1.36	4.31	205.77	74.85	4.96	15.29	0.30	45.79	2.6	5.65	11.4
	Subsoil	510.32	1.77	1.00	71.26	80.65	0.50	12.74	0.25	5.37	2.1	4.92	6.3
F-3	Andic	674.29	1.59	4.14	105.71	27.93	7.83	15.71	0.26	46.72	3.0	5.02	24.1
	Subsoil	725.00	1.90	1.00	30.00	49.00	0.50	10.00	0.10	4.30	2.3	5.38	14.8
F-4	Andic	1518.00	1.13	3.62	113.90	44.83	5.08	20.87	0.24	22.07	3.0	4.75	33.9
	Subsoil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	----	0.0
F-5	Andic	1174.17	1.41	5.83	222.33	47.00	16.75	13.17	0.35	147.00	4.5	4.56	25.0
	Subsoil	950.00	1.60	4.00	50.00	45.00	3.00	11.00	0.30	22.70	3.8	5.84	21.1
F-6	Andic	720.00	1.50	4.33	133.33	29.33	3.80	16.33	0.43	14.10	2.2	5.44	24.5
	Subsoil	807.14	1.90	1.00	25.00	73.43	0.50	11.00	0.31	6.70	3.0	5.45	11.0
F-7	Andic	1164.67	1.39	5.73	163.00	50.33	5.27	18.40	0.25	13.69	2.1	5.29	23.1
	Subsoil	1085.00	1.65	2.50	29.32	105.46	1.75	11.18	0.22	8.16	2.1	5.36	10.3
F-8	Andic	538.75	1.00	8.21	87.50	68.72	8.73	14.43	0.24	31.95	2.1	5.02	7.8
	Subsoil	890.00	1.20	4.50	56.50	83.50	2.75	13.50	0.20	34.80	1.8	5.03	10.7

Table 12. Ion concentrations, pH, and Ca/Mg ratio for 20-30 cm thick volcanic ash soil layers near Libby, Montana (Stark 1977).

Site Number	Growth Evaluation	Micrograms/Gram										
		Ca	Cu	Fe	K	Mg	Mn	Na	Zn	PO_4	pH	Ca/Mg
13	Very Slow	589	2.0	4.2	70	42	3.1	15	.57	11	6.2	14.0
14	Poor	962	1.6	4.1	203	85	3.7	16	.67	108	5.8	11.3
18	Poor	1575	0.9	2.6	202	76	5.9	16	.68	54	6.8	20.7
19	Poor	703	1.8	2.7	152	83	7.4	13	.47	129	6.7	8.5
15	Good	503	2.0	3.7	186	55	3.2	18	.92	20	6.3	9.1
33	Good	457	2.8	3.2	301	61	2.9	12	.62	213	6.6	7.5
34	Good	943	4.6	3.0	120	74	1.7	13	.48	38	7.5	12.7

Conifer requirements for manganese are still not well understood. Nitrate concentrations (ppm), which fluctuated considerably with site and layer, were inconclusive, as were the sodium levels. Phosphate (11 - 147 μg/g) was much more available in the andic than in the subsoil layer, but was below average concentration in some cases. The range of zinc (0.1 - 0.8 μg/g) was more favorable in the andic than in the subsoil, but was below average in most cases. Both andic and subsoil layers were very acid. This acid condition may be affecting the availability of some nutrients for tree growth, especially the micronutrients (Southhard 1969), making them less available for tree growth.

Calcium/magnesium ratios are generally expected to be in the range of 2/1 through 5/1 (Geist and Strickler 1970) for favorable tree growth. These values are not concrete, and the ratio limits at which problems may occur in tree growth are not well defined. The ratios present in many of the ash and subsoil layers appeared very high (Table 11).

Examination of the data in Table 12 does not lead to any positive conclusions concerning nutrient concentrations and tree growth. Site 13 exhibited the poorest growth for western larch and site 34 the best. Both sites appeared to have below average concentrations of magnesium, manganese, and phosphate. Calcium was normal for tree growth on site 34 and slightly low on site 13. Concentration of copper was above average for site 34. Potassium was below average for site 13. The pH on all sites was much higher than for the Kootenai National Forest samples, and the calcium/magnesium ratio exhibited the same mixed and relatively high trend.

Based solely on the concentration of available nutrients, the relative growth performance of the sites in Table 12 would be difficult to evaluate. For example, calcium levels on two of the three growth sites were below the average concentration usually associated with a fertile forest soil. Available potassium concentrations appeared to be above average on both good and poor growth sites. Calcium/magnesium ratios were high on all sites, while magnesium and phosphate levels were, in many cases, below average. Site factors other than nutrient availability appeared to be controlling the limits of growth potential on most of these sites. Comparison of the nutrient concentrations in Table 11 with those in Table 12 indicated that the Kootenai National Forest sites were as capable of producing good growth in western larch as the other sites in the Libby area. Available nutrient concentrations alone should not cause poor growth on the sites sampled in this study.

Summary of Soil Chemical Data Comparisons

The small number of significant differences among the nutrient concentrations and contents in the andic soil layers of the various drainage and land type classes (Table 13) were expected. Despite the apparent differences in the leaching rate of the andic soil suggested by the A2 horizon development, the overall fertility

Table 13. Summary of soil nutrient concentration (micrograms/gram) and availability (milliequivalents/square meter, kilograms/hectare) comparisons by three classification groupings for Kootenai National Forest sample sites.

Comparison by Grouping Classification	Ca			Cu			Fe			K			Mg			Mn			Na			Zn			Total Cations	PO_4			NO_3		Total N
	µg/g	meq/m^2	kg/ha	µg/g	meq/m^2	kg/ha	µg/g	meq/m^2	kg/ha	µg/g	meq/m^2	kg/ha	µg/g	meq/m^2	kg/ha	µg/g	meq/m^2	kg/ha	µg/g	meq/m^2	kg/ha	µg/g	meq/m^2	kg/ha	meq/ha	µg/g	meq/m^2	kg/ha	mg/l	weighted ppm	kg/ha
Drainage Classification A																															
Andic Comparisons																															
Slow to Moderate														S										M			S				
Slow to Rapid							R				R										S							S			
Moderate to Rapid							R	R			R									M	M			M							
Subsoil Comparisons																															
Slow to Moderate											S	S	S	S	S	S	S	S													S
Slow to Rapid			S	S	S	S		S				S		S	S	S	S	S	S	S	S	S	S	S	S						S
Moderate to Rapid				M	M	M			M										M	M		M	M	M							
Andic to Subsoil Comparisons																															
Slow		S	S	S	S	S	A	S		A	S		S	S	S	A	S		A	S	S		S		S	A	A	A	A	A	A
Moderate		S		S	S	S		S		A		A		S		A	A	A		S			S		S	A		A			A
Rapid		S			S		A		A	A		A	S	S		A	A	A	A	S			S	A	S	A	A	A			A
Drainage Classification B																															
Andic Comparisons																															
Slow to Moderate																		M						M		S	S				
Slow to Rapid																															
Moderate to Rapid						M	R																								
Subsoil Comparisons																															
Slow to Moderate			S			S			S	S		S	S	S	S	S	S	S								M					S
Slow to Rapid	S	S	S		S	S					S	S	S	S	S		S	S	S	S	S	S	S	S	S		R				S
Moderate to Rapid			M		M	M					M	M								M	M			M		R					
Andic to Subsoil Comparisons																															
Slow	S	S	S	S	S	S	A	S		A	S		S	S	S	A	S			S	S		S		S	A	A	A	A	A	A
Moderate		S		S	S	S	A	S	A	A		A	S	S	S	A	A	A	A	S			S		S	A		A	A	A	A
Rapid									A	A	A	A							A												
Land Type Classification																															
Andic Comparisons																															
351 to 352													1			2										1					
351 to 355		5									5											1			5						
352 to 355							5												2												
Subsoil Comparisons																															
351 to 352										1			1	1		1	1	1								2					1
351 to 355			1	1	1	1			1				1		1	1	1	1	1	1	1	1	1	1							1
352 to 355				2	2	2				5									2	2	2	2	2	2							
Andic to Subsoil Comparisons																															
351		S	S	S	S	S	A	S		A	S		S	S	S	A	S			S			S		S	A			A	A	A
352		S		S	S	S		S		A		S	S	S		A	A	A	A	S			S		S	A		A			A
355		S		S	S		A		A	A		A	S	S		A	A	A	A					A	S	A		A			A

S, M, R in the table indicates the drainage class having a significantly higher value for the comparison.

1, 2, 5 in the table signifies the last digit of the land type class having a significantly higher value for the comparison

($\alpha = .05$)

of the volcanic ash soils did not appear to be significantly affected by the drainage rate of the subsoil.

For the hypothesis concerning the relationship of soil fertility to subsoil drainage to be supported by the data, the more soluble cations, particularly sodium and potassium, needed to occur in significantly greater amounts in the subsoil on sites having the slowest subsurface drainage. Examination of the sodium comparison results (Table 13) indicated greater concentrations and availabilities with slower subsoil drainage. Potassium results were not as conclusive, but may have been affected by the tendency for soils to complex potassium into unavailable forms. Further examination of the comparison results (Table 13) for all three classification groupings revealed a trend among a number of the soil nutrients to occur in greater concentration or availability in the subsoil having the slower drainage rate.

In the absence of evidence of significantly different leaching rates in the volcanic ash soils over different subsoil drainage classes, the differences noted in nutrient concentration and content of the subsoil (Table 13) could not be attributed to differential illuviation of cations from the ash. These differences supported the hypothesis that differential accumulation of nutrients in the subsoil was related to differences in drainage rate and land type. In addition, differences in the physical composition of the parent materials, and the attendant differences in moisture regime, depth to bedrock, weathering rate, and other related factors played a part in the variation of nutrient concentrations and availabilities.

The number of significant differences among the concentrations and contents of soil nutrients was to be expected when the andic and subsoil layers of each drainage and land type class were compared (Table 13). The differences in the physical characteristics of the parent material accounted for a number of the observed relationships. The thickness differences between the subsoil and the andic layers, as well as variation in coarse fragment (>2mm) content, contributed to the large number of differences.

The microgram per gram concentrations of the soil cations allowed comparison on a unit weight basis of the fine fraction (<2mm) of the soil alone. Soil characteristics, such as bulk density, horizon thickness, and percentage coarse fragments (>2mm), were not considered. Geist and Strickler (1978) noted that differences in the outcome of comparisons using the two methods of expression should be expected. Differences were most prevalent in this study between comparisons by concentration and those using the milliequivalent per square meter measure of nutrient availability (Table 13). The results of kilogram per hectare and microgram per gram comparisons were not identical, but did tend to agree more closely as to which cations were the most abundant or available in the respective soil layers.

Comparisons based on the milliequivalent per square meter availability of the soil nutrients produced results (Table 13) that were biased by the failure to correct for coarse fragment (>2mm) volume in the calculations. The values obtained gave estimates of the quantity of each nutrient available for plant growth in the soil layers, as if each layer were composed only of material less than 2mm in size. The thickness, high bulk density, and coarse fragment (>2mm) volume, of the subsoil layers resulted in indications of much greater availability of most ions in the subsoil than was actually the case.

The comparisons based on kilogram per hectare availabilities of each soil nutrient incorporated the estimated volume of coarse fragments (>2mm) into the calculations (Table 13). The estimated percentage volume of coarse fragments was subtracted from the calculated volume of each respective soil horizon. The results of the tests for significance using these nutrient contents reflected more realistically the actual nutrient availabilities in the soil layers. Iron, potassium, manganese, phosphate, and total nitrogen availabilities exhibited a trend toward greater availability for plant growth in the andic soil layers, as compared to the subsoil layers, of the various drainage or land type classes.

Each method of comparison supported a different evaluation of the nutrient fertility of the soils sampled. Comparison on the basis of microgram per gram concentration provided the best measure of the extent to which nutrient accumulation in the subsoil might be occurring. Evaluation on the basis of nutrient content were somewhat more important for estimation of availability for tree growth.

Comparison of Drainage and Land Type Classification Groupings

Significant differences in the results of data comparisons obtained for each of the classification grouping systems used were noted (Tables 13 and 17). These differences resulted from the altering of the sample site distribution among classes in each grouping. The impetus for analyzing the data by three grouping schemes was to determine the most effective analysis technique.

Drainage classification A was based on the percolation rates used by the U.S.D.A. Soil Conservation Service (1974). Grouping, using a modification of the percolation classes to limit soil drainage rates to three categories, resulted in the most uniform division of sites of the three systems (Table 1). This method of site division resulted in considerable mixing of the physical characteristics associated with parent materials. In addition, the rapid drainage class consisted of widely diverse measured drainage rates (from 16.3 to 180 cm/hour), while the slow and moderate drainage classes were much more limited (Table 1).

Drainage classification B consisted of an arbitrary assignment of drainage rates to the slow, moderate, and rapid classes (Table 1). Site division among classes was less uniform than in classification A (Table 1). Measured drainage rates were grouped as closely as possible to naturally occurring breaks in rate. This method of grouping approximated more closely the division of sites by land type and minimized the mixing of parent materials in the subsoils of a drainage class.

The land type classification system was used as a grouping scheme for the sample sites because this is the system by which the Forest Service is presently mapping their forest lands. Resource management plans are made using the land type designations. An estimation of the applicability of this sytem, as compared to those using drainage rate, for analysis of the sample data was deemed appropriate. The land classes are based upon several site and soil factors in addition to subsoil drainage. Soil type and parent material are among the most important of these factors, so the mixing of parent materials among sample sites grouped by this classification was not a problem. The land types were associated broadly with drainage rates based on the subsoil parent material. In some cases there was overlap of drainage rates (Table 1) for the 352 and 355 land types as a result of peculiarities in the respective glacial till subsoils. Some 355 sites had very little or no glacial till subsoil over the bedrock, further confusing the parent material-drainage relationship.

In the soil data analyses few significant differences were noted in any of the classification systems (Table 13). Drainage classification A produced the greatest number of differences, but in no system did the nutrient content of the volcanic ash soil appear to be related to drainage rate or land type.

Numerous significant differences occurred in the comparison of subsoil data (Table 13). Many similarities were noted among the results, with differences being attributed primarily to the variation of subsoil distributions among the groupings. Drainage classification B produced the most significant differences in results of the subsoil comparisons.

The results of comparisons between the andic and subsoil layers of the various classes produced numerous significant differences (Table 13). The land type classification results and those of drainage classification A seemed comparable most often. The results obtained for comparisons in drainage classification B were compatible with those of the other classifications, but the rapid drainage class contained a notable lack of significant differences between the andic and subsoil layers.

Of the three classification systems, drainage classification B appeared to produce the most reasonable results for the soil nutrient comparisons. The minimal mixing of different subsoil types, and the division of drainage classes at naturally occurring breaks in drainage rate, enabled this system to produce more realistic comparisons than the other groupings. The mixing of parent materials among the classes of drainage classification A, and the overlap of subsoil drainage rates between land types 352 and 355, made comparison results obtained for these two systems of site classification less reliable.

Productivity Analysis

Tree Data Analysis

The results of t-test comparisons of means for tree growth parameters (breast height, 1.37 m), sapwood area/basal area ratio (breast height), and site index are presented in Table 14. Differences in the significant results noted were caused by the regrouping of sites to match differences in the classification systems.

Drainage Classification A (Slow, 0-5.1 cm/hr; Moderate, 5.1-15.2 cm/hr; Rapid, >15.2 cm/hr). No significant differences were noted for the innermost 2.54 cm of growth (Table 14). For the outermost 2.54 cm of growth, trees on the slowly drained sites had significantly more rings than those on sites with moderate or rapid drainage rates. The greater number of rings in the innermost 2.54 cm of growth would have indicated slower juvenile growth, had any significant differences been noted. For the outermost 2.54 cm, the greatest number of rings indicated slower recent growth. Recent growth indications showed that the trees on the slowly draining sites were growing more slowly than those on either the moderately or rapidly drained sites.

No significant differences among sapwood area/basal area ratios occurred in this classification (Table 14). No indication

Table 14. Results of drainage class and land type comparisons of sapwood area/basal area ratio (at 1.37 meters), tree growth parameters, and site index (Student's t-test).

Comparison	Sapwood Area / Basal Area	Innermost Rings per 2.54cm	Outermost Rings per 2.54cm	Site Index
Drainage Classification A				
Slow to Moderate			S	M
Slow to Rapid			S	R
Moderate to Rapid				
Drainage Classification B				
Slow to Moderate	S	M	S	M
Slow to Rapid	S	R	S	
Moderate to Rapid		R	M	
Land Type Classification				
351 to 352	351	352	351	
351 to 355		355	351	355
352 to 355	355	352		

S, M, R, or land type class in the table indicates the class having a significantly higher value or number.

($\alpha = .05$)

Drainage Classification A	Drainage Classification B	Land Type Classification
Slow n=48	Slow n=28	351 n=28
Moderate n=64	Moderate n=84	352 n=56
Rapid n=56	Rapid n=21	355 n=49

of differences in tree vigor could be obtained using this drainage grouping.

Site index was significantly higher on both the rapidly and moderately drained sites as compared to the sites having slowly draining soil (Table 14). These results contradicted the expected relationship between tree productivity and drainage rate. Tree growth, using this drainage grouping, was better for western larch on sites having the more rapid drainage.

Drainage Classification B (Slow, 0.254 cm/hr; Moderate, 2.54-25.4 cm/hr; Rapid, >25.4 cm/hr). The number of growth rings found in the innermost 2.54 cm of tree growth was significantly lower on slowly drained sites as compared to the number of rings in trees on sites with moderate and rapid subsoil drainage (Table 14). Trees growing on moderately drained soils had fewer rings in the innermost 2.54 cm at breast height than did those on rapidly drained soils. This relationship was reversed for the outermost 2.54 cm of tree growth. The trees growing on slowly drained sites had the greatest number of growth rings and those on more rapidly draining soils had fewer. These results indicated that juvenile growth and subsoil drainage rate were inversely related, while recent growth and subsoil drainage rate were directly related. Slowly drained sites produced the most rapid juvenile growth, but the slowest recent growth.

Sites having rapid subsoil drainage produced the slowest juvenile growth, but were producing the most rapid recent diameter growth. Moderately drained soils fell between the two extremes for both juvenile and recent growth rates.

Sapwood area/basal area ratio was greater on sites having slow drainage rates than on either moderately or rapidly drained sites (Table 14). These results indicated that the greatest tree vigor was to be found on the slowly draining sites, even though diameter growth was reduced.

Site index was significantly lower on slowly drained sites than on those with moderate drainage (Table 14).

The expected relationship between productivity measures such as site index and sapwood area/basal area ratio was an increase in productivity of sites with a decrease in drainage rate. The site index calculations in drainage classification A (Table 14) contradicted the expectation, and juvenile growth comparisons were too inconclusive to interpret strongly. Recent growth indications supported the site index results.

In this drainage classification (B) the results were more clearcut and contradictory (Table 14). Juvenile growth comparisons supported the expectation that timber productivity was better on slowly drained sites, while recent growth measurement comparisons indicated that rapidly drained soils were related to the best timber growth. Estimation of tree vigor by the sapwood area/basal area ratio produced significant results indicating that trees on the sites with slower drainage were the most vigorous. Logically, the most vigorous trees should be the most productive. Site index calculations, used as a measure of site productivity indicate that the moderately drained sites were producing better timber growth than those with slow drainage. The juvenile growth and tree vigor results were at odds with those obtained by recent growth and site index comparisons.

This contradiction could be explained in two ways, neither of which was conclusive given the available data. Sapwood area/ basal area ratio was a comparative measure of tree vigor and not necessarily a measure of radial growth. The trees on the slowly drained sites may have reached a stage in their growth where more energy was being expended in crown expansion or root development than on stem volume production. Heavy stocking and the compacted glacial till subsoil of the slowly drained sites had concentrated the root systems of the trees in the andic layer of the profile. The concentration of roots in the andic layer was more prevalent on slowly drained sites than on those with more rapid drainage, limiting nutrient availability on the slowly drained sites to the nutrients found in the andic soil layer. Trees growing on sites having more rapid drainage would have the additional nutrient stores of the subsoil horizons available to them. Despite comparable levels of nutrients in the volcanic ash soils of the three sites, competition for those nutrients may have been much more intensive among the trees on the slowly drained soils. Confinement of roots to the andic layer, and a slightly higher stocking density (Appendix 6) than soils with moderate or rapid drainage, would contribute to the competition on the sites having the compacted till and slow subsoil drainage.

Because the comparisons among nutrient levels in the soil were based upon mean values for the drainage classes, there may have been masked differences in availability of some nutrients among the sample sites. This could have led to nutrient deficiencies which would have restricted growth somewhat, even though the capability to move sufficient moisture (greatest sapwood area) was unimpaired. The nutrient level comparisons in Table 9 indicated that calcium and potassium were less available on slowly drained ash horizons than on rapidly drained soils. The lack of significantly different sodium levels in the andic soils indicated that leaching was not the cause of the lower calcium and potassium.

Nutrient depletion by tree growth could explain both phenomena. Trees on the slowly drained sites may have reached a transition stage in the development of the stand. Initial establishment and growth of the stand was rapid and unimpaired, but factors such as stocking density, confinement of roots to the thin andic soil, and depletion of essential cations by intense competition may have caused a decline in the overall vigor which had not yet been reflected in the sapwood area/basal area ratio.

Precipitation is approximately 91 cm for the slowly drained sites and 86-112 cm for the moderately and rapidly drained sites. The map and graph in Appendix 17 were used to determine annual precipitation rates. The capacity for water movement in trees was greater on the sites having the lowest precipitation rates. The capacity for water movement in trees was greater on the sites having the lowest precipitation, indicating that availability of water was not a problem for those trees, and consequently not a factor in the reduced timber growth.

Land Type Classification. Soils on the 351 land type supported trees having significantly fewer growth rings per innermost 2.54 cm growth (breast height) than sites of either 352 or 355 types (Table 14). Trees on the 352 land type had fewer rings per inner 2.54 cm of growth than those on 355 land types. The number of rings in the outermost 2.54 cm of growth was significantly higher for trees on the 351 type when compared to the outermost 2.54 cm of growth in trees on the 352 or 355 type sites. These results provided an indication that juvenile western larch growth was fastest on the more compacted glacial till subsoils, and slowest on those having a thin till subsoil over bedrock. Recent growth was slowest on the sites having the compacted till subsoil.

Sapwood area/basal area ratio was lower for trees growing on the 352 land type than for those on 351 and 355 sites (Table 14). Tree vigor was shown to be higher on sites having compacted glacial till subsoils and thin glacial till over bedrock, and lower on those with the deep, loose glacial till subsoils of the 352 class.

Site index was significantly higher for trees growing on the 355 land type as compared to those on 351 sites (Table 14).

Although not as clearcut as the results for drainage classification B (Table 14), the land type grouping results (Table 14) supported the same apparent contradiction in site productivity. Juvenile growth was best on the 351 (slowly drained) sites, while recent radial growth was slowest. The site index measure of productivity indicated that 355 (rapidly drained) sites supported better height growth than 351 (slowly drained) sites. Trees growing on the 351 (slowly drained) sites were significantly more vigorous than those on 352 sites (moderately drained). The indication of greater tree vigor on 355 sites (rapidly drained) than on 352 (moderately drained) sites was the only evidence in all three classification system comparisons (Table 14) that tree vigor might be greater on sites having thin glacial till subsoil over bedrock. Drainage rates associated with land types were the original estimates of approximate drainage class based on subsoil characteristics.

Xylem Sap Analysis

Drainage Classification A (Slow, 0-5.1 cm/hr; Moderate, 5.1-15.2 cm/hr; Rapid, > 15.2 cm/hr). Xylem sap from trees growing on slowly drained sites contained greater amounts of potassium and phosphate than that from trees on rapidly drained sites (Table 15). Sap extracted from trees growing on moderately drained soils contained less potassium and more manganese than that from trees growing on slowly drained sites, and more phosphate than that from trees on sites with rapid drainage.

The results of the xylem sap nutrient comparisons were compared to those from the andic soil nutrient comparisons (Table 13) to give insight into the relationships between soil and sap nutrient concentrations. Phosphate levels in the ash soils were significantly higher in slowly drained soils as compared to those on moderately or rapidly drained sites. Manganese exhibited no significant relationship. Potassium occurred in greater availability on rapidly drained sites when compared to those having slow or moderate drainage. The potassium and manganese levels in the sap may have been the result of compensatory uptake of these cations in response to an increased energy expenditure by the trees in obtaining them. The mixing of noncompacted glacial till subsoil into the slowly drained class in this classification grouping allowed some root penetration, and the occurrance of higher potassium and manganese

Table 15. Results of the comparisons of the nutrient concentrations of xylem sap (milligrams/liter) from trees on sample sites grouped by drainage class and land type (Student's t-test).

Comparison	Milligrams/Liter (PPM)									
	Ca	Cu	Fe	K	Mg	Mn	Na	Zn	PO_4	Total N
Drainage Classification A										
Slow to Moderate				S		M				
Slow to Rapid				S					S	
Moderate to Rapid									M	
Drainage Classification B										
Slow to Moderate						M	S	S		
Slow to Rapid			R							
Moderate to Rapid				M						
Land Type Classification										
351 to 352		351	352				351	351		351
351 to 355				351		355				
352 to 355		355		352				355		355

S, M, R, or land type class in the table indicates the class having a significantly higher concentration.

(α = .05)

Drainage Classification A	Drainage Classification B	Land Type Classification
Slow n=14	Slow n=11	351 n=11
Moderate n=10	Moderate n=17	352 n=9
Rapid n=6	Rapid n=2	355 n=10

levels in the subsoil of slowly drained sites (Table 13), may have accounted for the higher potassium and magnesium levels. The higher soil phosphate levels were reflected only in sap from trees growing on slowly and moderately drained sites. Apparently the trees growing on the moderately drained sites were able to overcome the significantly lower soil phosphate content present on those sites, as compared to those draining slowly. The higher phosphate concentration may have been the result of root expansion into the subsoil where additional phosphate was available.

Drainage Classification B (Slow, 0-2.54 cm/hr; Moderate, 2.54-25.4 cm/hr; Rapid, > 25.4 cm/hr). The content of xylem sap from trees on slowly drained sites was lower in manganese and higher in sodium and zinc than that of sap from trees on sites with moderate drainage (Table 15). Trees on rapidly draining sites had more iron in the xylem sap than those on sites which drained slowly, and less potassium than trees on moderately drained sites.

Comparison of the xylem sap results to those of the andic soil comparison (Table 13) produced contradicting results for zinc and sodium. Andic soil layers contained greater amounts or concentrations of both cations in moderately drained soils as compared to slowly drained soils. Trees on slowly drained sites had more of the cations in the xylem sap than did trees on moderately drained sites. The higher consumption of sodium and zinc on sites where they were found in lower availability cannot be explained. Neither element is required in large amounts for tree growth, and their concentration seemed unusual. The high potassium level in xylem sap from trees on moderately drained sites may have resulted from additional sources of potassium within easy reach of roots expanding into the subsoil. Lower iron in the xylem sap of trees on slowly drained sites as compared to levels in sap from trees on rapidly drained soils may have reflected a soil deficiency in iron resulting from heavy competition for nutrients in the andic layer of the slowly drained sites. Root expansion on the slowly drained sites was limited by the compacted till layer. Only the nutrients available in the ash layers were available to the trees for use in growth, and in heavily stocked stands competition for available ions would be heavy.

Land Type Classification. The xylem sap of trees growing on the 351 land type contained significantly higher levels of copper, sodium, zinc, and total nigrogen than that of trees from the 352 type (Table 15). Sap taken from trees growing on the shallow till of the 355 land type contained more copper, zinc, and phosphate than that from trees on the deep loose till of 352 sites, and more manganese than that from trees on the compacted till of the 351 type. Potassium content of sap from trees on land types 351 and 352 was higher than that of sap from trees growing on 355 sites.

The significant results observed in the comparisons of xylem sap nutrient contents among land types did not reflect the significant results obtained by comparing the andic soil nutrient levels (Tables 13 and 15). Xylem sap from the trees showing the least recent growth and lowest site index (growing over compacted till on land type 351) contained higher levels of a number of cations than trees growing on 352 land type sites. These same trees were the most vigorous, exhibiting the largest sapwood area/basal area ratios (Table 14) of the three land types. The significantly higher vigor of the trees on slowly drained sites appeared to enable them to obtain nutrients under adverse conditions, as opposed to contributing to height and volume production. This indication of energy expenditure to obtain nutrients would help to explain the contradiction noted between the tree vigor and site index estimates of site productivity capability.

Moisture Stress Analysis

The moisture stress in trees on sites grouped according to drainage classification A was significantly lower on sites having slow drainage, as compared to either the moderate or rapid drainage classes (Table 16).

Grouping of sites by drainage classification B resulted in significantly higher moisture stress in trees growing on rapidly drained soils than in trees on soils having either slow or moderate drainage (Table 16). Trees growing in soil which was drained at a

Table 16 Results of tree moisture stress comparisons on sites grouped by drainage and land type classification systems (Student's t-test).

Comparison	Stress (megaPascals)
Drainage Classification A	
Slow to Moderate	M
Slow to Rapid	R
Moderate to Rapid	
Drainage Classification B	
Slow to Moderate	M
Slow to Rapid	R
Moderate to Rapid	R
Land Type Classification	
351 to 352	352
351 to 355	355
352 to 355	

M, R, or land type indicates the class having the significantly greater moisture stress at the time of measurement.

(α = .05)

Drainage Classification A	Drainage Classification B	Land Type Classification
Slow n=43	Slow n=31	351 n=31
Moderate n=43	Moderate n=73	352 n=51
Rapid n=44	Rapid n=26	355 n=48

moderate rate were under higher moisture stress than those on slowly drained sites.

When sample sites were sorted by land type the trees growing over the compacted glacial till of the 351 type were under significantly lower stresses than trees on sites of either the 352 or 355 types (Table 16).

The results of moisture stress comparisons within all three classification groupings supported the same conclusion (Table 16). Moisture stress in trees on rapidly drained soils, or those having thin glacial till subsoils over bedrock, was the highest measured. Trees on slowly drained soils, or those having compacted, deep glacial till subsoils, were under the least stress. Stress in trees on moderately drained soils or on sites having deep, loose glacial till subsoil, fell between that of those growing on the other two sites. Moisture availability appeared strongly related to drainage rate and land type.

Summary of Productivity Data

Tree Data Analysis. On the basis of the data comparisons, timber productivity of a site appeared related to the subsurface drainage (Table 17). The contention that sapwood area/basal area ratio is indicative of tree vigor (Waring *et al.*1980) suggested that trees on the slowly drained, or land type 351, sites were significantly more vigorous than those on the other two site classes. The indication of vigor

Table 17. Summary table of sample tree data, xylem sap nutrient concentration, and moisture stress measurement comparisons by three classification groupings for Kootenai National Forest sample sites.

Comparisons by Grouping Classification	Sample Tree Data: Sapwood Area/Basal Area	No. Rings/Inner 2.54 cm	No. Rings/Outer 2.54 cm	Site Index	Xylem Sap Chemical Analysis ---Milligrams/Liter---: Ca	Cu	Fe	K	Mg	Mn	Na	Zn	PO_4	Total N	Moisture Stress Mega-Pascals
Drainage Classification A															
Slow to Moderate		M	S	M				S		M					M
Slow to Rapid			S	R				S					S		R
Moderate to Rapid													M		
Drainage Classification B															
Slow to Moderate	S	M	S	M						M	S	S			M
Slow to Rapid	S	R	S				R								R
Moderate to Rapid		R	M					M							R
Land Type System															
351 to 352	1	2	1			1	2				1	1		1	2
351 to 355		5	1	5				1		5					5
352 to 355	5	2				5		2				5		5	

S, M, R in the table indicates the drainage class having a significantly higher value for the comparison.

1, 2, 5 in the table signifies the last digit of the land type class having a significantly higher value for the comparison.

(α = .05)

was based on the supposition that these trees were able to conduct most readily the moisture needed to support vigorous growth. Juvenile and recent growth rates varied with drainage rate; the former, indirectly, and the latter, directly. Data comparisons based on land type classes did not produce significant differences as distinctly indicative of relationships in subsoil characteristics, but did tend toward agreement. The somewhat confusing results were the result of mixed drainage rates among the subsoils of the land type classes.

The relationship among the number of rings per 2.54 cm in the most recent growth seemingly contradicted the indication that the slowly drained sites supported the most vigorous tree growth (Table 17). Comparisons showed that the trees on the rapidly drained sites have put on the greatest radial growth in the recent past, followed by the moderately drained and slowly drained sites, in that order. An explanation of this contradiction was based on the limiting of root growth on the slowly drained sites by the compacted till subsoil, and the possible nutrient depletion of the andic soil layer by heavy stocking and the resultant strong competition for nutrients.

Loewenstein (1977) noted a similar situation in the growth of Douglas-fir. Seedlings which were established in areas of low phosphorus availability grew well until the roots, confined to the ash layer, had depleted the available supply. Geist (1974) stressed the importance of root distribution in order to make use of the total nutrient potential of a site. Mader (1968) reported a similar situation to that on the Kootenai sample sites. Early tree growth was somewhat superior on plots having a fertile, thin topsoil over infertile sand, as compared to growth on a somewhat less fertile, but deep fine-textured soil nearby. As later demands for moisture and nutrients increased, the growth rates were reversed, and the site having the more totally available moisture and nutrient supplies produced greater height and volume growth.

With favorable conditions western larch grows rapidly from the seedling stage and may be 1.3 meters tall in four years (U.S.D.A. Forest Service 1965). Tree height and moderate diameter growth continue to age 75-100 years, after which diameter growth becomes dominant (Larsen 1916). As a species, western larch tends toward a relatively large, well-developed root system which protects it against windthrow (Kotok 1973, Larsen 1916). Evidence of windthrow was more prevalent on the slowly drained or 351 land types than on those of the other classes. This trend toward increased blowdown was an indication that the root systems of trees on the affected sites were being limited in their development.

Xylem Sap Analysis. The significance of results for tests done on nutrient levels in sap from trees growing on rapidly drained soils of drainage classification B were suspect (Table 17). Only two samples fell into the rapid class and both were from the same site. Interpretations were weakened by this fact.

The results of the xylem sap data comparisons for all classifications indicated comparable levels of nutrient concentration for many of the nutrients in the sap (Table 17). This relationship indicated that most trees were able to obtain comparable amounts of the various nutrients from the soil. The comparable nutrient levels in all classes supported the suggestion that the significantly greater vigor of the trees on slowly drained soils (as indicated by the sapwood area/basal area ratio was serving to support root growth and competition for soil nutrients, rather than height growth.

The nutrients for which significant differences in concentration existed seemed to be grouped. Those trees growing on the slowly drained sites appeared to have higher concentrations of sodium and the micronutrients (copper and zinc), while those having higher concentrations of the macronutrients (iron, potassium, and phosphate) were growing on sites having the more rapid drainage rates. The potassium and phosphate comparisons in drainage class A indicated higher concentrations of these two nutrients in trees on slowly drained sites (Table 17). In this classification, however, two of the six sites had deep, loose till subsoils which allowed penetration of the feeder roots and additional nutrient uptake. These results were repeated only for potassium in the 351 to 355 land type comparisons.

Moisture Stress Analysis. Results of the t-tests performed on the data from moisture stress testing on trees in the sample site areas indicated that stress on the sites of the rapidly drained or 355 land type class was the greatest (Table 17). Stress was lowest on those trees growing on the sites of land class 351, those having the slowest drainage. Differences among the three classes were significant. This relationship indicated that available moisture for trees growing in andic soils over differently drained subsoils would become a growth-limiting factor for trees at different times. The most rapidly drained sites would become limited first, and the slowest, last, during any year. Reduced radial growth of the trees on the slowly drained sites, as compared to those on the moderately and rapidly drained sites, was probably not caused by lack of available moisture. Roe (1956) reported very slow growth in larch under competition induced moisture stress, but this did not appear to be the case in this area. The indication of the sapwood area/basal area ratio, that moisture was not limiting, was substantiated. Factors other than moisture were responsible for the reduced growth on the slowly drained sites.

Volcanic ash soils have a high moisture holding capacity and are able to provide large portions of their available water to plants at low moisture stress limits (Geist and Strickler 1978). The significantly higher stress found in trees over more rapidly drained soils, or on the shallow glacial till and bedrock of land type 355 and the deep, loose glacial till of type 352, indicated a more rapid loss of soil moisture than was noted for the more slowly drained or land type class 351 soils. As most site characteristics such as stocking, aspect, slope, thickness of the volcanic ash layer, and so on, were comparable, the differences in moisture stress must have resulted from subsurface drainage.

The shallow depth to bedrock would account for the greatest moisture stress having occurred on the most rapidly drained or 355 land type sites. The weaker structure of the coarse soils formed in the deeper glacial till of the moderately drained or 352 sites would result in a lower moisture holding capacity than the more compacted till of the slowly drained or 351 land type soils. In addition, the compacted till layer would tend to maintain a condition of moisture availability somewhat above field capacity for a longer period in the spring and early summer. This situation would be especially true on lower slopes as the slow percolation rates of the compacted till would cause downslope movement of water along the volcanic ash-subsoil interface. More rapidly drained soils would experience much less of this downslope gravitational movement of water.

Comparison of Drainage and Land Type Classification Grouping

The most complete and consistent results of the comparisons for tree data were obtained using classification B (Table 17). Drainage classification A produced few significant results from the tree data comparison, likely a result of the heterogeneity of subsoil composition within classes. Results obtained through the land type system corresponded to, but were less definitive than, those of classification B. The soil drainage inconsistencies in types 352 and 355 could account for the differences noted in significant results.

The moisture stress relationship to subsurface drainage appeared to be best explained by the results of drainage classification B (Table 17). The parent material and drainage inconsistencies noted for drainage classification A and the land type system, respectively, were the probable cause for the lack of a significant result in the moderate to rapid drainage class, and 352 to 355 land type, comparisons of moisture stress data.

The land type system produced the greatest number of significant results among comparisons of the xylem sap nutrient contents (Table 17). Results obtained by drainage classification A corresponded closely to those of the land type system, but fewer than half the number of significant differences were noted among the comparisons. The results of drainage classification A did not correspond favorably with those of either of the other two systems. Little information exists concerning nutrient concentrations in the xylem sap of forest trees. As a consequence, it was difficult to determine which of the comparisons produced the most realistic and reliable results. Because drainage classification B had been chosen most representative of the field conditions encountered, it was chosen as the most representative of xylem sap contents.

Drainage classification B was determined to best approximate the natural breaks in soil drainage and subsoil parent material types for the sample sites in this study. The land type classification system did not match the continuity of results produced by drainage classification B for the various soil and site aspects examined. Drainage classification A produced results exhibiting even less continuity than the land type system.

Because the land type system is currently in use on the Kootenai National Forest as a management tool, it will be used in predicting comparative nutrient availabilities and timber productivity for diverse areas of the forest. The limited scope of this study cannot be extrapolated to state that drainage classification is a better management tool than land typing. On large areas of concern, the variation of soil drainage may negate its usefulness as a predictor of productivity. Basing the land type classification system on a number of soil and site factors has made its applicability more meaningful in general situations, as opposed to the specific.

CONCLUSIONS

Soil nutrient concentrations and availability, timber productivity measurements, xylem sap nutrient content, and moisture stress measurements were analyzed and compared on the basis of two drainage classification groupings and the Forest Service land type system. Most reliable results were obtained when drainage rates were designated: 0 to 2.54 cm/hour, slow; 2.54 to >25.4 cm/hour, moderate; and >25.4 cm/hour, rapid. This system was designed to incorporate natural breaks in the measured drainage rates of the site examined.

The primary hypothesis, that fertility of soils having andic soil layers is significantly affected by the rate of drainage through the subsoil, received considerable support in this study. The analysis of data and comparison of means for the various nutrient concentrations in the andic layers of the profiles sampled did not show significant differences with change in drainage class. On the basis of this work it appeared that leaching of volcanic ash soils by comparable precipitation input did not significantly affect the nutrient status of the andic layers, regardless of subsoil drainage rate. Comparable leaching of the ash layers occurred on all sites.

Analysis of subsoil data indicated that differential leaching of the subsoil with changing drainage rate was occurring. Soil nutrients were significantly more abundant in the slowly drained subsoils than in those with more rapid drainage. Physical differences in the parent materials and varying depth to bedrock contributed to nutrient differences in the subsoil, especially in terms of nutrient availability per unit area. If the physical differences in parent material had not occurred on these sites, a more concrete conclusion concerning the primary hypothesis might have been drawn. The data appeared to confirm that the overall fertility of andic soils was related to drainage rate. Natural variability among site factors indicated other possible contributions to the variation in fertility.

Interpretations of the secondary hypothesis concerning the relationship of forest productivity to subsoil drainage were more complex.

Radial tree growth on slowly drained soils was significantly faster than on either moderately or rapidly drained sites following stand establishment. The vigor of this stand, as determined by sapwood area/basal area ratio, was still significantly greater, but growth rate on both the moderately and rapidly drained sites was higher. Depth of the feeder root systems of the trees on the slowly drained sites was limited primarily to the volcanic ash soil by a compacted layer of glacial till. On the sites having moderate and rapid drainage, the feeder roots were not as limited in their potential for expansion and penetrated to greater depths.

Xylem extract analysis indicated possible iron deficiency on the slowly drained sites. Levels of iron were significantly lower in sap from trees on those sites as compared to trees growing on rapidly drained sites. The data were inconclusive because the sample size for rapidly drained sites was very small.

Moisture stress measurements made on trees in August, 1980, showed that rapidly drained soils had the most severe moisture stress. Available moisture was in greatest abundance on the slowly drained sites. The moisture holding capacity of volcanic ash soils appeared to be dependent upon the rate of water movement through subsurface layers as well as the texture and structure of the andic horizons themselves.

The higher moisture stress on the moderately and rapidly drained sites explained the lower sapwood area/basal area ratio on these sites, as compared to those with slow drainage. Moisture stress appeared to be a major limiting factor for tree productivity (vigor) on the more rapidly drained sites.

Competition among the root systems of trees for the available nutrients in the andic soils of the slowly drained sites appeared to be a major factor in the reduced radial growth of trees on these sites. Possible deficiency of available iron in the andic layer was another contributing factor. Large sapwood area/basal area ratio indicated that moisture availability was less a problem on the slowly drained sites than on those draining more rapidly. The dbh measurements of sample trees were comparable on all sites.

Timber productivity of andic soils could not be explained by the variation in nutrient availability with variation in subsurface drainage for the soils examined in this study. Some suggestion of nutrient limitation of growth on the slowly drained sites was noted, but data interpretations were inconclusive. Drainage variation did affect tree growth and productivity on andic soils as it contributed to moisture availability and freedom of expansion for the feeder root system.

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APPENDIX 1

Land Type Descriptions

(From: U.S. Forest Service Land Type System
Kootenai National Forest)

LAND TYPE 351

Deep glacial till generally overlain by loessial deposit.

Surface 10-16 inches yellowish brown silt loam, very weakly aggregated, slightly sticky, nonplastic, very rapidly permeable, rock content 10-25 percent. Subsurface 1-2 feet pale brown to light gray very fine sandy loam, slightly plastic, firm, hard, 30-50 percent subangular to subrounded gravels and cobbles. Substrata is indurated and depth to bedrock is 40-120 inches.

This unit is characterized by the closely spaced, parallel, first order drainages that are deeply incised. It is mostly on northerly aspects at elevations of 3000-4600 feet with slope gradients 40-65 percent. Overland flow occurs frequently and subsurface runoff is concentrated fairly rapidly. Generally has 1st order streams flowing into 3rd and 4th order streams.

The average annual precipitation is from 25-35 inches with 20-40 percent occurring as snow. The possibility of rain-on-snow flooding is medium to low. Annual runoff is 7-14 inches, and the peak discharge from this unit will take place in the early to mid portion of the melt season. The overland flow potential is very high on this unit due to the likelihood of a compacted, impervious layer occurring at 2-4 feet depths in the soil. The evapotranspiration demand is low and soil water stresses in the surface foot can be expected by early to mid July in a normal growing season.

LAND TYPE 351

Identifying characteristics

slope <65%

Landform key glaciated

% outcropping rock --

bedrock control without

drainage pattern parallel 1st order into 3rd or 4th

stream entrenchment deep

drainage density high

age of deposit quaternary

plasticity slightly

particle size silt to boulder

sorting poorly

rock content of soil < 50%

material compacted glacial till

loess 10-16"

frost churning low

slope position and/or landform description mid to lower slopes

Implications

mass failure high

erosion potential high

drainage requirements sensitive - see Forest Hydrologist

cut slope ratio 1½:1

fill slope ratio 1½:1

CBR range 11-28

logging system low suitability - advanced system needed

compaction factor (roads) possible swell due to compacted till

compaction potential (equipment) moderate

seismic needs may need seismics to determine rippability of compact till

revegetation moderately fast

ground water pollution potential low

surface runoff potential high

road suitability low

miscellaneous frequent overland flow

LAND TYPE 352

Deep glacial till overlain by loessial deposit.

Surface 10-18 inches yellowish brown silt loam, very weakly aggregated, slightly sticky, nonplastic, very rapidly permeable. Subsurface light gray to white fine sandy loam, aggregated, slightly sticky, slightly plastic, moderately rapid permeability. Depth to bedrock ranges from 60-140 inches. Rock content in the surface is 10-25 percent mostly in gravel and cobble size. Subsurface rock content ranges from 30-50 percent, mostly as subangular and subrounded gravels and cobbles.

This unit occurs mainly on northerly aspects at elevations of 3000-5800 feet on slopes with gradients of 35-65 percent. The slopes are generally long and uniform. Drainageways are widely spaced and only slightly entrenched with fairly long reaches. Overland flow is rare and percolation is deep.

The average annual precipitation ranges from 30 to greater than 40 inches on this wide-spread unit with the majority of the unit in the 35-40 inch zone with 40-50 percent occurring as snow. The possibility of rain-on-snow flooding is medium to low. Average annual runoff for the majority of the unit is 14-20 inches, and the peak discharge will occur in the mid portion of the melt season. The overland flow potential is medium to low. The evapotranspiration demand is low and soil water stresses in the surface foot can be expected by late July in a normal growing season.

LAND TYPE 352 (364)

Identifying Characteristics

slope $<$65%

Landform key glacial deposit

% outcropping rock --

bedrock control without

drainage pattern dendritic

stream entrenchment slight

drainage density widely spaced

age of deposit quaternary (Wisc.)

plasticity slightly

particle size silt to boulder

sorting poorly

rock content of soil 30-50%

material non-calcareous

loess 10-18"

frost churning moderate

slope position and/or landform description "run-of-the-mill till"

Implications

mass failure moderate

erosion potential moderate

drainage requirements normal

cut slope ratio 1½:1

fill slope ratio 1½:1

CBR range 7-28 depends on rock content in till

logging system no restrictions

compaction factor (roads) shrink - w/some oversize

compaction potential (equipment) moderate

seismic needs --

revegetation moderately fast

ground water pollution potential low

surface runoff potential moderate

road suitability moderate

miscellaneous overland flow rare - percolation deep

LAND TYPE 355

Moderately shallow galcial till of fine and very fine sandy loam overlain by loessial deposit.

Surface 8-16 inches yellowish brown silt loam, very weakly aggregated, slightly sticky, slightly plastic, rapidly permeable. Subsurface light gray to white fine sandy loam, aggregated, slightly sticky, slightly plastic, moderate permeability. Rock content ranges from 15-25 percent in the surface to 30-45 percent in the subsurface and the rocks are subrounded to subangular in shape and are mostly gravels and cobbles in size.

This unit is generally associated with land type 353 and has been extensively scoured. It occurs at elevations of 3500-6000 feet. Slope shape is generally convex and slope gradient ranges from 25-55 percent.

The average annual precipitation is 40 inches or greater for this unit with 50 percent occurring as snow. The possibility of rain-on-snow flooding is medium to high. Annual runoff is 20 inches or greater, and the peak discharge will be late in the melt season. The overland flow potential is medium. The evapotranspiration demand is medium to low and soil water stresses can be expected from early to mid July for this unit.

LAND TYPE 355 (356) (358)

Identifying Characteristics

slope < 50%

age of deposit quaternary

Landform key depositional-glacial till

plasticity slightly

% outcropping rock 0-25%

particle size silt to boulder to bedrock

bedrock control with

sorting poorly

drainage pattern dendritic

rock content of soil 30-45%

stream entrenchment

material metasedimentary (non-calcareous)

drainage density low and moderate

loess 8-16"

frost churning moderate

slope position and/or landform description glacial deposit-convex

Implications

mass failure moderate

erosion potential moderate

drainage requirements normal

cut slope ratio 1½:1

fill slope ratio 1½:1

CBR range 7-28 depends on rock content in till

logging system no restrictions

compaction factor (roads) shrink - till swell-rock oversize

compaction potential (equipment) moderate

seismic needs some seismic data due to % of rock outcrop and shallow rock

revegetation moderate

ground water pollution potential low to moderate

surface runoff potential medium

road suitability moderate

miscellaneous

APPENDIX 2

Site Selection Criteria

SITE SELECTION CRITERIA

Site	Elevation (ft.)	Aspect	Slope	Precipitation (in.)	Depth of Ash (in.)	Habitat Type	Stocking (stems/acre)	Elevation (m)	Precipitation (cm)	Depth of Ash (cm)	Stocking (stems/ha)
S-1	4080	N10°E	53%	36	7	TSHE/CLUN	580	1244	91.4	17.8	1433
S-2	4080	N34°E	53%	36	12	TSHE/CLUN	871	1244	91.4	30.5	2151
S-3	4080	N22°E	54%	36	12	TSHE/CLUN	774	1244	91.4	30.5	1292
S-4	4080	N18°E	56%	36	9	TSHE/CLUN	774	1244	91.4	22.9	1292
M-1	3920	N28°W	44%	34.5	12	TSHE/CLUN	968	1195	87.6	30.5	2391
M-2	3960	N16°E	36%	34.7	12	TSHE/CLUN	823	1207	88.1	30.5	2033
M-3	4200	N48°W	41%	37.5	11	TSHE/CLUN	532	1280	95.3	27.9	1314
M-4	4320	N60°E	43%	39	12	THPL/CLUN	678	1317	99.1	30.5	1675
M-5	4360	N42°E	40%	39.5	14	THPL/CLUN	532	1329	100.3	35.6	1314
M-6	4600	N16°W	39%	43	12	TSHE/CLUN	532	1402	109.2	30.5	1314
M-7	4580	N25°W	40%	42.6	12	TSHE/CLUN	387	1396	108.2	30.5	956
M-8	4640	N45°W	55%	44	14	TSHE/CLUN	484	1414	111.8	35.6	1195
F-1	4080	N38°E	51%	36	10	TSHE/CLUN	774	1244	91.4	25.4	1912
F-2	4200	N34°E	53%	37.6	13	TSHE/CLUN	678	1280	95.5	33.0	1675
F-3	4200	N2°W	53%	37.6	14	TSHE/CLUN	436	1280	95.5	35.6	1077
F-4	4200	N21°E	62%	37.6	21*	TSHE/CLUN	436	1280	95.5	53.3	1077
F-5	4160	N14°E	57%	37.3	12	TSHE/CLUN	484	1268	94.7	30.5	1195
F-6	4000	N45°W	53%	35.4	12	TSHE/CLUN	436	1219	89.9	30.5	1077
F-7	4680	N58°W	43%	44.2	15	TSHE/CLUN	581	1426	112.3	38.1	1435
F-8	4640	N6°E	51%	44	20	TSHE/CLUN	532	1414	111.8	50.8	1314

* with mixing

APPENDIX 3

Sample Site Locations

Sample Site Locations

SITE	SECTION	TOWNSHIP	RANGE	DETAIL
S-1	SW 1/4 of NE 1/4 of 25	33N	32W	1.1 mi. SE on 4064 from Little Tom Mtn. turnoff. 110 ft. uphill from top of road cut.
S-2	SW 1/4 of NE 1/4 of 25	33N	32W	190 ft. up road from S-1. 58 ft. uphill from top of road cut.
S-3	SW 1/4 of NE 1/4 of 25	33N	32W	69 ft. up road from S-2. 95 ft. uphill from top of road cut.
S-4	SW 1/4 of NE 1/4 of 25	33N	32W	110 ft. up road from S-3. 75 ft. uphill from top of roadcut.
M-1	NW 1/4 of SW 1/4 of 23	33N	32W	Road end 1.1 mi. from right turn off road 4654, 0.3 mi. from jct. of roads 4654 and 600. 115 ft. downhill from road at end.
M-2	SW 1/4 of SW 1/4 of 23	33N	32W	Road end 1.1 mi. from right turnoff road 4654, 0.3 mi. from jct. of roads 4654 and 600. 210 ft. along contour of road beyond road's end.
M-3	SW 1/4 of SW 1/4 of 23	33N	32W	West edge of clearcut at road end, 1.1 mi. from right turnoff road 4654, 0.3 mi. from jct of roads 4654 and 600. 80 ft. east of upper west corner of clearcut and 175 ft. uphill from clearcut edge.
M-4	NE 1/4 of NE 1/4 of 21	33N	32W	2.8 mi. from jct. roads 4653 and 4653-C along 4653-C. 215 ft. downhill from road.
M-5	NE 1/4 of NE 1/4 of 21	33N	32W	2.8 mi. from jct roads 4653 and 4653-C along 4653-C. 115 ft. downhill from road and 53 ft. west along the contour.
M-6	SE 1/4 of SE 1/4 of 16	33N	32W	4.05 mi. from jct roads 4653 and 4653-C along 4653-C. 121 ft. uphill from road.
M-7	SE 1/4 of SE 1/4 of 16	33N	32W	4.15 mi. from jct. roads 4653 and 4653-C along 4653-C. 90 ft. uphill from road.

SITE	SECTION	TOWNSHIP	RANGE	DETAIL
M-8	SE 1/4 of SW 1/4 of 16	33N	32W	4.15 mi. from jct. roads 4653 and 4653-C along 4653-C. 225 ft. uphill from the road.
F-1	SW 1/4 of NE 1/4 of 25	33N	32W	1.2 miles from Little Tom Mtn. road turnoff along road 4604. 25 ft. from top of road cut.
F-2	SW 1/4 of NE 1/4 of 25	33N	32W	1.65 miles from the Little Tom Mtn. road turnoff along road 4604. 125 ft. from top of road cut.
F-3	SW 1/4 of SW 1/4 of 23	33N	32W	West edge of clearcut at road end, 1.1 mi. from right turnoff road 4654, 0.3 mi. from jct of roads 4654 and 600. 115 ft. from easterly edge of clearcut, 135 ft. uphill from upper edge of clearcut.
F-4	SE 1/4 of SW 1/4 of 23	33N	32W	West edge of clearcut at road end, 1.1 mi. from right turnoff road 4654, 0.3 mi. from jct. of roads 4654 and 600. 30 ft. easterly on contour from upper-east corner of clearcut.
F-5	SE 1/4 of SW 1/4 of 23	33N	32W	West edge of clearcut at road end, 1.1 mi. from right turnoff road 4654, 0.3 mi. from jct. of roads 4654 and 600. 80 ft. downhill from upper east corner of clearcut and 30 ft. east along contour from clearcut boundary.
F-6	SW 1/4 of SW 1/4 of 23	33N	32W	West edge of clearcut at road end, 1.1 mi. from right turnoff road 4654, 0.3 mi. from jct. of roads 4654 and 600. 195 ft. uphill from road edge and 164 feet from east edge of clearcut.
F-7	SW 1/4 of SE 1/4 of 16	33N	32W	3.8 mi. from jct. roads 4653 and 4653-C along 4653-C. 100 ft. uphill from road.
F-8	SW 1/4 of SE 1/4 of 16	33N	32W	3.95 mi. from jct roads 4653 and 4653-C along 4653-C. 95 ft. uphill from road.

APPENDIX 4

Soil Profile Descriptions

S-1

Classification: Andic Dystrochrept, loamy-skeletal, mixed, frigid.

Location: Lincoln County, MT. SW¼ of NE¼ of Sec. 25, T33N, R32W.

Physiographic position: Hill slope, 4,080 ft. (1,244 m) elevation.

Topography: Slightly concave, 53% slope, N10^{O}E aspect.

Drainage: Moderately well drained, moderate percolation, considered to have slow darainage for this study.

Vegetation: Larix occidentalis, Thuja plicata, Abies grandis, Pinus contorta, Pseudotsuga menziesii, Tsuga heterophylla, Alnus sinuata, Salix sp., Acer glabrum, Pachistima myrsinites, Vaccinium globulare, Streptopus amplexifolius, Viola orbiculata, Goodyera oblongifolia.

Parent Material: Volcanic ash over compacted glacial till.

Sampled by: C. Sptizner, August 20, 1980.

Remarks: Coarse fragments rounded and subrounded throughout; rooting primarily in ash layers; few undergrowth plants.

01-02 2.5-0 inches (6.35-0 cm).

B21 0-1.5 inches (0-3.8 cm). Very pale brown (10 YR 7/3) silt loam, dark yellowish brown (10 YR 4/6) moist; weak, medium, granular structure; soft (dry), friable (moist), slightly sticky and slightly plastic (wet); many very fine and fine, common medium, and few coarse roots; many very fine, fine, and medium vesicular pores; 10% gravels; acid (pH 5.7); clear, wavy boundary.

B22 1.5-7 inches (3.8-18 cm). Very pale brown (10 YR 7/4) silt loam, yellowish brown (10 YR 5/6) moist; weak, medium, granular structure; soft (dry), friable (moist), slightly sticky and slightly plastic (wet); many very fine, fine, and medium vesicular pores; 10% gravels; acid (pH 5.8); abrupt wavy boundary.

IIA2 7-9 inches (18-23 cm). Discontinuous pockets; white (5 Y 8/1) gravelly silt loam, pale yellow (5 Y 7/4) moist; moderate, fine, subangular blocky structure; slightly hard (dry), firm (moist), slightly sticky and slightly plastic (wet); few very fine and fine roots; many very fine and fine discontinuous irregular pores; 30% gravels, 15% cobbles; clear, broken boundary.

IIA&B 7-14 inches (18-36 cm). White (5 Y 8/1) very gravelly silt loam, pale yellow (5 Y 8/4) moist; common, medium, distinct mottles, olive (5 Y 5/4), olive brown (2.54 4/4) moist; moderate, medium, subangular blocky structure; hard (dry), very firm (moist), slightly sticky and plastic (wet); few, thin, silt films lining the interstitial pores; few very fine and fine roots; common, very fine and fine, and few medium discontinuous interstitial pores; 35% gravels, 15% cobbles; acid (pH 5.2); gradual, wavy boundary.

S-1 cont'd.

IIB&A	14-26 inches (36-66 cm). White (5 Y 8/1) very gravelly silt loam, light yellowish brown (2.5 Y 6/4) moist; many medium, distinct mottles, pale yellow (2.5 Y 7/4), olive brown (2.5 Y 4/4) moist; strong, medium, subangular blocky structure; hard (dry), very firm (moist), slightly sticky and plastic (wet); few, thin, silt films lining interstitial pores; few very fine and fine roots; common very fine and fine, and few medium discontinuous interstitial pores; 35% gravels, 15% cobbles; acid (pH 5.1); clear, wavy boundary.
IIIB2	26-40+ inches (66-102+ cm). Very pale brown (10 YR 8/4) gravelly silt loam, yellowish brown (10 YR 5/8) moist; strong, medium, subangular blocky structure; hard (dry) very firm (moist), slightly sticky and plastic (wet); few, thin silt flows lining interstitial pores; few very fine and fine roots; common very fine and fine, and few medium discontinuous interstitial pores; 25% gravels; acid (pH 5.2).

S-2

Classification:	Andic Dystrochrept, coarse-silty over loamy-skeletal, mixed, frigid.
Location:	Lincoln County, MT. SW¼ of NE¼ of Sec. 25, T33N, R32W.
Physiographic position:	Hill slope, 4,080 ft. (1,244 m) elevation.
Topography:	Slightly convex, 53% slope, N34^{O}E aspect
Drainage:	Moderately well drained, moderate percolation, considered to have slow drainage for this study.
Vegetation:	_Larix occidentalis_, _Thuja plicata_, _Pseudotsuga menziesii_, _Acer glabrum_, _Abies grandis_, _Tsuga heterophylla_, _Alnus sinuata_, _Pachistima myrsinites_, _Rubus parviflorus_; _Viola orbiculata_, _Streptopus amplexifolius_.
Parent material:	Volcanic ash over compacted glacial till.
Sampled by:	C. Spitzner, August 7, 1980.
Remarks:	Coarse fragments rounded and subrounded in till but appears to be weathering heavily; some angular coarse fragments in the loess layer; most rooting in the loess layer; evidence of tree throw prominent; discontinuous A2, very difficult to describe; IIA2 varies to B3 on occasion.
01 & 02	1.5-0 inches (3.8-0 cm).
A2	0-0.5 inches (0-1.3 cm). Silt loam; weak, medium, granular structure; soft (dry), very friable (moist), slightly sticky and slightly plastic (wet); many very fine and fine, common medium and coarse roots, many very fine, fine, and medium vesicular pores; 15% gravels, 5% stones; clear, wavy boundary.
B21	0.5-7 inches (1.3-18 cm). Very pale brown (10 YR 7/4) gravelly silt loam, dark yellowish brown (10 YR 4/6) moist; weak medium granular structure; soft (dry), very friable (moist), slightly sticky and nonplastic (wet); many very fine and fine, common medium and coarse roots; many very fine, fine, and medium vesicular pores; 15% gravels, <5% stones; acid (pH 5.7); clear wavy boundary.
B22	7-12 inches (18-30 cm). Yellow (10 YR 7/6) gravelly silt loam, yellowish brown (10 YR 5/8) moist; weak, medium, granular structure; soft (dry), very friable (moist), slightly sticky and nonplastic (wet); many very fine and fine, common meduim and coarse roots; many very fine, fine, medium, vesicular pores; 15% gravels, <5% stones; acid (pH 5.74); abrupt, wavy boundary.

S-2 cont'd.

IIA2 — 12-15 inches (30-38 cm). White (2.5 Y 8/2) very gravelly silt loam, pale yellow (2.5 Y 7/4) moist; moderate, medium, subangular blocky structure; slightly hard (dry), friable (moist), slightly sticky and plastic (wet); common fine and few medium roots; many very fine and common fine discontinuous interstitial pores; 50% gravels; acid (pH 5.25); clear, broken boundary.

IIA&B — 15-18 inches (38-46 cm). White (2.5 Y 8/2) very gravelly silt loam, light gray (2.5 Y 7/2) moist; common, fine, faint mottles, light yellowish brown (2.5 Y 6/4), olive brown (2.5 Y 4/4) moist; strong, coarse to very coarse, subangular blocky structure, slightly hard (dry), very firm (moist), sticky and plastic (wet); very few to few, thin silt flows in pores; few fine and medium roots; many very fine and common fine discontinuous interstitial pores; 55% gravels, 15% cobbles; acid (pH 5.35); clear, wavy boundary.

IIB&A — 18-34 inches (46-86 cm). White (5 Y 8/2) very gravelly silt loam, light gray (2.5 Y 7/2) moist; common, medium, faint mottles, light olive brown (2.5 Y 5/4), olive brown (2.5 Y 4/4) moist; strong, coarse, subangular blocky structure; slightly hard (dry), very firm (moist), sticky and plastic (wet); few, thin silt flows in pores; few fine roots; many very fine, common fine pores; 55% gravels, 10% cobbles; acid (pH 5.19); abrupt, wavy boundary.

IIB2 — 34-40+ inches (86-102+ cm). White (2.5 Y 8/2) gravelly silt loam, pale yellow (2.5 Y 7/4) moist; common, coarse, distinct mottles, light yellowish brown (2.5 Y 6/4), light olive brown (2.5 Y 5/6) strong, very coarse subangular blocky structure; slightly hard (dry), very firm (moist), sticky and plastic (wet); few, thin silt flows in pores; few fine roots; few very fine and fine discontinuous interstitial pores ; 20% gravels; acid (pH 5.20).

S-3

Classification: Andic Dystrochrept, coarse-silty over loamy-skeletal, mixed, frigid.

Location: Lincoln County, MT. SW¼ of NE¼ of Sec. 25, T33N, R32W.

Physiographic position: Hill slope, 4,080 ft. (1,244 m) elevation.

Topography: Slightly concave, 54% slope, N22^{o}E aspect.

Drainage: Moderately well drained, moderate percolation, considered to have slow drainage for this study.

Vegetation: *Thuja plicata*, *Larix occidentalis*, *Pseudotsuga menziesii*, *Abies grandis*, *Tsuga heterophylla*, *Alnus sinuata*, *Salix* sp., *Acer glabrum*, *Pachistima myrsinites*, *Rosa* sp., *Clintonia uniflora*, *Viola orbiculata*, *Streptopus amplexifolius*, *Rubus parviflorus*.

Parent material: Volcanic ash over compacted glacial till.

Sampled by: C. Spitzner and G. Newman, August 21, 1980.

Remarks: Coarse fragments rounded and subrounded throughout.

01 & 02 2.5-0 inches (6.4-0 cm).

B21 0-7 inches (0-18 cm). Pink (7.5 YR 7/4) silt loam, dark yellowish brown (10 YR 4/6) moist; weak, medium, granular structure; soft (dry), very friable (moist), slightly sticky and slightly plastic; many very fine, fine, medium, and few coarse roots; many very fine, fine, medium vesicular pores; 15% gravels, <5% cobbles; acid (pH 5.56); clear, wavy boundary.

B22 7-12 inches (18-30.5 cm). Very pale brown (10 YR 7/4) silt loam, dark yellowish brown (10 YR 4/6) moist; weak, medium, granular structure; soft (dry), very friable (moist), slightly sticky and slightly plastic (wet); many very fine, fine, medium,and few coarse roots; many fine, very fine, medium vesicular pores; 15% gravels; acid (pH 5.91); abrupt, wavy boundary.

IIA2 12-18 inches (30.5-46 cm). White (10 YR 8/2) gravelly sandy loam, pale yellow (2.5 Y 7/4) moist; moderate, fine, subangular blocky structure; slightly hard (dry), firm (moist), slightly sticky and slightly plastic (wet); few, thin silt flows in pores; common fine and few medium roots; many fine and common medium discontinuous irregular pores; 30% gravels, 15% cobbles; acid (pH 5.66); clear wavy boundary.

S-3 cont'd.

IIB&A 18-31 inches (46-79 cm). White (10 YR 8/2) very gravelly silt loam, light yellowish brown (2.5 Y 6/4) moist; common, medium, distinct mottles, pale brown (10 YR 6/3), dark yellowish brown (10 YR 4/6) moist; strong, medium, subangular blocky structure; hard (dry), very firm (moist), sticky and plastic (wet); few, thin silt flows in pores; few fine and medium roots; many fine and common medium discontinuous irregular pores; 35% gravels, 20% cobbles, acid (pH 4.98); gradual wavy boundary.

IIB2 31-40+ inches (46-102+ cm). White (2.5 Y 8/2) gravelly silt loam, pale yellow (2.5 Y 7/4) moist; many, coarse, distinct mottles, light yellowish brown (10 YR 6/4), yellowish brown (10 YR 5/4) moist; strong, medium, subangular blocky structure; hard (dry), very firm (moist), sticky and plastic (wet); few, thin silt flows in pores; no roots; many fine and common medium discontinuous irregular pores; 30% gravels, 15% cobbles; acid (pH 5.22).

S-4

Classification: Andic Dystrochrept, loamy-skeletal, mixed, frigid.

Location: Lincoln County, MT SW¼ of NE¼ of Sec. 25, T33N, R32W.

Physiographic position: Hill slope, 4,080 ft. (1,244 m) elevation.

Topography: Slightly concave, 56% slope, N18^{o}E aspect.

Drainage: Moderately well drained, moderate percolation, considered to have slow drainage for this study.

Vegetation: Thuja plicata, Larix occidentalis, Pseudotsuga menziesii, Abies grandis, Alnus sinuata, Acer glabrum, Salix sp., Tsuga heterophylla.

Parent material: Volcanic ash over compacted glacial till.

Sampled by: C. Spitzner, August 22, 1980.

Remarks: Coarse fragments rounded and subrounded; slightly more clay than other S-pits; rooting heaviest at lower edge of B22; some continue downward along rock faces and through cracks.

O1&O2 3-0 inches (7.6-0 cm).

B21 0-3 inches (0-7.6 cm). Pink (7.5 YR 7/4) silt loam, dark brown (7.5 YR 3/4) moist; weak, medium, granular; soft (dry very friable) (moist), slightly sticky and slightly plastic (wet); many very fine, fine, medium, and common coarse roots; many very fine, fine, and medium vesicular pores; 10% gravels, <5% cobbles; acid (pH 5.60); clear, wavy boundary.

B22 3-9 inches (7.6-23 cm). Very pale brown (10 YR 7/3) silt loam, dark yellowish brown (10 YR 4/6) moist; weak, medium, granular structure; soft (dry), very friable (moist), slightly sticky and slightly plastic (wet); many very fine, fine, medium, and common coarse roots; many very fine, fine, and medium vesicular pores; 10% gravels, <5% cobbles; acid (pH 5.49); abrupt, wavy boundary.

IIA2 9-14 inches (23-36 cm). White (10 YR 8/2) gravelly sandy loam, light yellowish brown (10 YR 6/4) moist; moderate, medium subangular blocky structure; slightly hard (dry), firm (moist), nonsticky and slightly plastic (wet); common very fine, fine, medium, and few coarse roots; many very fine, common fine and medium discontinuous irregular pores; 25% gravels, 10% cobbles; acid (pH 5.04); clear,wavy boundary.

IIA&B 14-20 inches (36-51 cm). White (10 YR 8/2) gravelly silt loam, pale yellow (2.5 Y 4/4) moist; few, fine, faint mottles, light olive brown (2.5 Y 5/4), olive brown, (2.5 Y 4/4) moist; strong, medium, subangular blocky structure; hard (dry), firm (moist), slightly sticky and plastic (wet); few, thin silt flows in pores; common very fine and fine roots; many very fine and fine, and common medium discontinuous interstitial pores; 30% gravels, 10% stones, 15% cobbles; acid (pH 5.17); gradual, wavy boundary.

S-4 cont'd.

IIB&A 20-31 inches (51-79 cm). White (2.5 Y 8/2) gravelly silt loam, pale yellow (2.5 Y 7/4) moist; common, fine, distinct mottles, light olive brown (2.5 Y 5/6), olive brown (2.5 Y 4/4) moist; strong, medium, subangular blocky structure; hard (dry), firm (moist), slightly sticky and plastic (wet); few, thin silt flows in pores; few very fine and fine roots; many very fine, common fine and medium discontinuous interstitial pores; 15% cobbles, 15% stones, 30% gravels; acid (pH 5.11); gradual, wavy boundary.

IIB2 31-41+ inches (79-104+ cm). Pale yellow (2.5 Y 8/4) gravelly silt loam, light yellowish brown (2.5 Y 6/4) moist; many, medium, distinct mottles, yellowish brown (10 YR 5/8), dark yellowish brown (10 YR 3/6) moist; strong, medium, subangular blocky structure; hard (dry), very firm (moist), sticky and plastic (wet); few, thin silt flows in pores; very few, thin clay flows in pores; few very fine and fine roots; common fine and medium discontinuous interstitial pores; 15% cobbles, 15% stones, 30% gravels; acid (pH 4.92).

M-1

Classification: Andic Dystrochrept, loamy-skeletal, mixed, frigid.

Location: Lincoln County, MT. NW¼ of SW¼ of Sec. 23, T33N, R32W.

Physiographic position: Hill slope, 3,920 ft. (1,195 m) elevation.

Topography: Slightly convex, 44% slope, N28^{O}W aspect.

Drainage: Moderately well drained, moderate percolation, considered to have moderate drainage for this study.

Vegetation: _Larix occidentalis_, _Pseudotsuga menziesii_, _Thuja plicata_, _Picea engelmannii_, _Tsuga heterophylla_, _Salix_ sp., _Arnica cordifolia_, _Pachistima myrsinites_, _Rubus parviflorus_, _Linnaea borealis_, _Chimaphila umbellata_, _Viola orbiculata_, _Listera_ sp., _Clintonia uniflora_, _Ribes_ sp., _Spirea betulifolia_, _Pyrola_ sp., _Menziesia ferruginea_, _Vaccinium globulare_, _Vaccinium caespitasum_, _Pteridium aquilinium_.

Parent material: Volcanic ash over glacial till.

Sampled by: C. Spitzner, August 29, 1980.

Remarks: Angular, subangular, and subrounded coarse fragments throughout; rooting primarily in the loess horizons with some penetration through the A22 where restriction occurs.

01&02 3-0 inches (7.6-0 cm).

A2 0-1.5 inches (0-4 cm). White (7.5 YR 8/0) sandy loam, gray to light gray (10 YR 6/1) moist; weak, medium, granular structure; soft (dry), very friable (moist), slightly sticky and nonplastic (wet); many very fine and fine roots; many very fine, fine, and medium vesicular pores; <10% gravels; acid (pH 4.31); clear wavy boundary.

B21 1.5-7 inches (4-18 cm). Brownish yellow (10 YR 5/6) cobbly silt loam, dark yellowish brown (10 YR 3/6) moist; weak, medium, granular structure; soft (dry), very friable (moist), slightly sticky and slightly plastic (wet); many very fine, fine, medium, and coarse roots; many very fine, fine, medium vesicular pores; 10% gravels, 25% cobbles; acid (pH 4.92); clear, wavy boundary.

B22 7-12 inches (18-30.5 cm). Light yellowish brown (10 YR 6/4) cobbly silt loam, dark yellowish brown (10 YR 4/6) moist; weak, medium, granular structure; soft (dry), very friable (moist), slightly sticky and slightly plastic (wet); many very fine, fine, medium and few coarse roots; many very fine, fine, and medium vesicular pores; 20% gravels, 20% cobbles; acid (pH 5.06); abrupt, wavy boundary.

M-1 cont'd.

IIA21	12-18 inches (30.5-46 cm). White (10 YR 8/2) very gravelly sandy loam, light yellowish brown (2.5 Y 6/4) moist; weak, medium, subangular blocky structure; soft (dry), friable (moist), slightly sticky and nonplastic (wet); common very fine and fine, and few medium roots; many very fine, fine, medium discontinuous interstitial pores; acid (pH 4.7); clear irregular boundary.
IIA22	18-33 inches (46-84 cm). White (2.5 Y 8/2) cobbly sandy loam, light yellowish brown (2.5 Y 6/4) moist; moderate, coarse, granular structure; soft (dry), friable (moist), slightly sticky and non-plastic (wet); common very fine, fine, medium roots; many very fine, fine, medium discontinuous interstitial pores; 20% gravels, 50% cobbles, 10% stones; acid (pH 4.69); clear irregular boundary.
IIB&A	33-40+ inches (84-102+cm). White (5 Y 8/1) cobbly silt loam, light yellowish brown (2.5 Y 6/4) moist; many medium to coarse, distinct mottles, light yellowish brown (10 YR 6/4), yellowish brown (10 YR 5/4) moist; moderate, medium, subangular blocky structure; hard (dry), firm (moist), slightly sticky and slightly plastic (wet); common, moderately thick silt flows lining pores; few very fine and fine roots, many very fine, fine, medium discontinuous irregular pores; 10% gravels, 50% cobbles, 10% stones; acid (pH 4.78).

M-2

Classification: Andic Eutrochrept, coarse-loamy over loamy-skeletal, mixed, frigid.

Location: Lincoln County, MT. SW¼ of SW¼ of Sec. 23, T33N, R32W.

Physiographic position: Hill slope, 3,960 ft. (1,207 m) elevation.

Topography: Slightly concave, 36% slope, N16°E aspect.

Drainage: Moderately well drained, moderately rapid percolation, considered to have moderate drainage for this study.

Vegetation: Tsuga heterophylla, Pseudotsuga menziesii, Larix occidentalis, Pinus contorta, Thuja plicata, Picea engelmannii, Alnus sinuata, Clintonia uniflora, Pachistima myrsinites, Arnica cardifolia, Linnaea borealis, Viola orbiculata, Vaccinium globulare, Listera sp., Goodyera oblongifolia, Rubus parviflorus, Menziesia ferruginia, Pyrola sp., Chimaphila umbellata, Ribes sp., Pteridium aquilinium.

Parent material: Volcanic ash over glacial till.

Sampled by: C. Spitzner, August 28, 1980.

Remarks: All coarse fragments rounded, subrounded, or subangular; rooting primarily above the loess--subsoil interface.

01+02 1.5-0 inches (3.8-0 cm)

A2 0-0.5 inches (0-1.3 cm). White (10 YR 8/1) silt loam, gray (10 YR 5/1) moist; weak, medium, granular structure; soft (dry), very friable (moist), slightly sticky and slightly plastic (wet); many very fine, fine, medium roots; many very fine, fine, medium vesicular pores; acid (pH 4.88); abrupt, broken boundary.

B21 0.5-6 inches (1.3-15 cm). Very pale brown (10 YR 7/4) cobbly silt loam, dark yellowish brown (10 YR 3/6) moist; weak, medium, granular structure; soft (dry), very friable (moist), slightly sticky and slightly plastic (wet); many very fine, fine, medium and coarse roots; many very fine, fine, medium vesicular pores; 10% gravels, 20% cobbles; acid (pH 5.31); clear, wavy boundary.

B22 6-12 inches (15-30.5 cm). Very pale brown (10 YR 7/4) cobbly silt loam, dark yellowish brown (10 YR 4/6) moist; weak, medium, granular structure; soft (dry), very friable (moist), slightly sticky and slightly plastic (wet); many very fine, fine, medium, and few coarse roots; many very fine, fine, medium vesicular pores; 10% gravels, 20% cobbles; acid (pH 5.06); abrupt, wavy boundary.

M-2 cont'd.

IIA2	12-19 inches (30.5-48 cm). White (2.5 Y 8/2) very gravelly sandy loam, pale yellow (2.5 Y 7/4) moist; weak, fine subangular blocky structure; soft (dry), friable (moist), slightly sticky and slightly plastic (wet); common very fine and fine, and few medium roots; many very fine, fine, and medium discontinuous irregular pores; 35% gravels, 25% gravels, <5% stones; acid (pH 5.51); clear wavy boundary.
IIA&B	19-27 inches (48-69 cm). White (2.5 Y 8/2) very cobbly sandy loam, light yellowish brown (2.5 Y 6/4) moist; weak, medium, subangular blocky structure; slightly hard (dry), firm (moist), slightly sticky and slightly plastic (wet); few, thin silt flows in pores; few very fine and fine roots; many very fine, fine, medium discontinuous irregular pores; 25% gravels, 40% cobbles; acid (pH 5.35); clear, wavy boundary.
IIB&A	27-40+ inches (69-102+ cm). White (2.5 Y 8/2) very cobbly sandy loam, light yellowish brown (2.5 Y 6/4) moist; common, fine, distinct mottles, reddish yellow (7.5 YR 7/6), dark brown (7.5 YR 3/4) moist; moderate, medium, subangular blocky structure; slightly hard (dry), firm (moist), slightly sticky and slightly plastic (wet); common, thin silt flows in pores; few very fine and fine roots; common very fine and many fine and medium discontinuous irregular pores; 20% gravels, 45% cobbles; acid (pH 6.25).

M-3

Classification: Andic Dystrochrept, coarse-silty over loamy-skeletal, mixed, frigid.

Location: Lincoln County, MT. SW¼ of SW¼ of Sec. 23, T33N, R32W.

Physiographic position: Hill slope, 4,200 ft. (1,280 m) elevation.

Topography: Slightly convex, 41% slope, N48^{O}W aspect.

Drainage: Moderately well drained, moderately rapid percolation, considered to have moderate drainage for this study.

Vegetation: *Larix occidentalis*, *Pinus contorta*, *Pseudotsuga menziesii* *Thuja plicata*, *Tsuga heterophylla*, *Picea engelmannii* *Salix* sp., *Alnus sinuata*, *Pyrola* sp., *Arnica cordifolia*, *Listera* sp., *Pachistima myrisnites*, *Viola orbiculata*, *Epilobium angustifolium*, *Shepherdia canadensis*, *Menziesia ferruginea*, *Ribes* sp., *Rubus parviflorus*, *Spirea betulifolia*, *Linnaea borealis*, *Goodyera oblongifolia*.

Parent material: Volcanic ash over glacial till.

Sampled by: C. Spitzner, August 27, 1980

Remarks: Pronounced tonguing in IIB&A, possibly a result of animal activity; rooting primarily above the B3.

O1&O2 1.5-0 inches (3.8-0 cm)

A2 0-0.5 inches (0-1.3 cm). White (10 YR 8/1) silt loam, grayish brown (10 YR 5/2) moist; weak, medium, granular structure; soft (dry), very friable (moist), slightly sticky and slightly plastic (wet); many very fine and common fine roots; many very fine and fine vesicular pores; acid (pH 4.01); abrupt, broken boundary.

B2 0.5-9 inches (1.3-23 cm). Light yellowish brown (10 YR 6/4) silt loam, dark yellowish brown (10 YR 4/4) moist; weak, medium, granular structure; soft (dry), very friable (moist), slightly sticky and slightly plastic (wet); many very fine, fine, medium, and coarse roots; many very fine, fine, medium vesicular pores; 10% gravels; acid (pH 4.80); abrupt, wavy boundary.

B3 9-11 inches (23-28 cm). White (10 YR 8/2) silt loam, pale brown (10 YR 6/3) moist; weak, medium, granular to subangular blocky structure; soft (dry), friable (moist), slightly sticky and slightly plastic (wet); common very fine and fine, and few medium roots; many very fine, fine, and medium vesicular pores; 10% gravels; acid (pH 5.05); abrupt, broken boundary.

M-3 cont'd.

IIA2	11-12 inches (28-30.5 cm). White (2.5 Y 8/2) gravelly sandy loam, light yellowish brown (2.5 Y 6/4) moist; weak, fine, subangular blocky structure; soft (dry), friable (moist), slightly sticky and slightly plastic (wet); common very fine and few fine roots; many very fine and fine, and common medium irregular discontinuous pores; 25% gravels; acidic (pH 5.16); clear, broken boundary.
IIA&B	12-19 inches (30.5-48 cm). White (2.5 Y 8/2) gravelly sandy loam, light gray (2.5 Y 7/2) moist; weak, medium, subangular blocky structure; slightly hard (dry), firm (moist), slightly sticky and slightly plastic (wet); very few, thin silt films in pores; few very fine and fine roots; many very fine, fine, and medium discontinuous interstitial pores; 25% gravels, <10% cobbles; acid (pH 5.10); clear, wavy boundary.
IIB&A	19-31 inches (48-79 cm). White (2.5 Y 8/2) very gravelly sandy loam, pale yellow (2.5 Y 7/4) moist; many, fine, distinct mottles, light yellowish brown (2.5 Y 6/4), light olive brown (2.5 & 5/4) moist; moderate, medium, subangular blocky structure; slightly hard (dry), firm (moist), slightly sticky and slightly plastic (wet); few, thin silt films in pores; few very fine and fine roots; many very fine, fine, and medium irregular discontinuous pores; 35% gravels, 20% cobbles, 10% stones; acid (pH 5.03); clear, wavy boundary.
IIIC	31-40+ inches (79-102+ cm). White (2.5 Y 8/2) very gravelly silt loam, light yellowish brown (2.5 Y 6/4) moist; strong, medium, subangular blocky structure; hard (dry), firm (moist), slightly sticky and plastic (wet); common thin silt films in pores; no roots; common very fine, many fine and medium , few coarse discontinuous irregular pores. 35% gravels, 10% cobbles; acid (pH 5.39).
IIA2 TONGUES	24-34 inches (61-86 cm). White (5 Y 8/1) gravelly sandy loam, light gray (2.5 Y 7/2) moist; common, fine, distinct mottles, light yellowish brown (10 YR 6/4), dark yellowish brown (2.5 Y 3/6) moist, weak, fine subangular blocky structure; soft (dry), friable (moist), slightly sticky and slightly plastic (wet); common very fine and fine roots; many very fine, fine, moderate discontinuous irregular pores; 20% gravels, acid (pH 4.82).

M-4

Classification: Eutric Glossoboralf, coarse-silty over loamy-skeletal, mixed, frigid.

Location: Lincoln County, MT. NE¼ of NE¼ of Sec. 21, T33N, R32W.

Physiographic position: Upper valley slope, 4,320 ft. (1,317 m) elevation.

Topography: Slightly convex, 43% slope, N60^{o}E aspect.

Drainage: Moderately well drained, moderately rapid percolation, considered to have moderate drainage for this study.

Vegetation: Larix occidentalis, Pseudotsuga menziesii, Pinus contorta, Thuja plicata, Picea engelmannii, Abies grandis, Arnica cordifolia, Pachistima myrisinites, Clintonia uniflora, Vaccinium globulare, Shepherdia canadensis, Rubus parviflorus, Chimaphila umbellata, Linnea borealis, Goodyera oblongifolia, Streptopus amplexifolius, Viola orbiculata, Rosa sp., Pteridium aquilinium.

Parent material: Volcanic ash over glacial till.

Sampled by: C. Spitzner, August 6, 1980.

Remarks: Coarse fragments are subangular and subrounded; primary rooting is above IIA2, but fine roots do go further down; tree throw common in this area.

01+02 1-0 inches (2.5-0 cm).

A2 0-1 inches (0-2.5 cm). Silt loam; weak, medium, granular structure; very friable (moist), slightly sticky and slightly plastic (wet); many very fine and fine roots; many very fine, fine, and medium vesicular pores; acid (pH 4.72); abrupt, broken boundary.

B21ir 1-2 inches (2.5-5.1 cm). Pale brown (10 YR 6/3) silt loam, dark yellowish brown (10 YR 3/4) moist; weak, medium, granular structure; very friable (moist), slightly sticky and slightly plastic (wet); many very fine and fine roots; many very fine, fine, and medium vesicular pores; acid (pH 5.30); abrupt, broken boundary.

B22 2-5 inches (5.1-12.7 cm). Very pale brown (10 YR 8/4) silt loam, dark yellowish brown (10 YR 3/6) moist; weak, medium, granular structure; very friable (moist), slightly sticky and slightly plastic (wet); many very fine, fine, and medium, and common coarse roots; many very fine, fine, medium vesicular pores; 5% gravels, 5% cobbles; acid (pH 5.8); abrupt, wavy boundary.

B23 5-8.5 inches (12.7-21.6 cm). Very pale brown (10 YR 7/4) silt loam, dark yellowish brown (10 YR 4/6) moist; weak, medium, granular structure; very friable (moist), slightly sticky and slightly plastic(wet); many very fine, fine, and medium, and common coarse roots; many very fine, fine, medium vesicular pores; 5% gravels, 5% cobbles; acid (pH 5.98); clear, wavy boundary.

M-4 cont'd.

B3	8.5-12 inches (21.6-30 cm). Very pale brown (10 YR 7/4) gravelly silt loam, dark yellowish brown (10 YR 4/6) moist; weak, medium, granular structure, friable (moist), slightly sticky and slightly plastic (wet); many very fine, fine, and medium, and common coarse roots; many very fine, fine, and medium vesicular pores; 20% gravels; acid (pH 5.98); clear, wavy boundary.
IIA2	12-16 inches (30.5-40.6 cm). White (2.5 Y 8/2) gravelly silt loam, light yellowish brown (2.5 Y 6/4) moist; moderate, medium, subangular blocky structure; friable (moist), slightly sticky and slightly plastic (wet); common very fine, fine, and medium, and few coarse roots; many very fine and common fine discontinuous irregular pores; 25% gravels, 10% cobbles; acid (pH 5.78); abrupt, wavy boundary.
IIB21t	16-19 inches (40.6-48 cm). White (2.5 Y 8/2) gravelly silt loam, pale yellow (2.5 Y 7/4) moist; strong, coarse, subangular blocky structure; firm (moist), sticky, plastic (wet); very few, thin clay skins in pores; few very fine, fine, medium roots; common very fine and medium and many fine discontinuous irregular pores; 30% gravels, 15% cobbles, 15% stones; acid (pH 5.55); clear, wavy boundary.
IIB22	19-29 inches (48-74 cm). White (2.5 Y 8/2) gravelly silt loam, pale yellow (2.5 Y 7/4) moist; many, fine, faint mottles, pale yellow (2.5 Y 7/4), light olive brown (2.5 Y 5/4) moist; moderate, medium, subangular blocky structure; firm (moist), slightly sticky and slightly plastic (wet); few, thin silt flows in pores; many very fine and few fine roots on rock faces; common very fine and medium, and many fine irregular pores; 30% gravels, 10% cobbles, 10% stones; acid (pH 5.3); clear, wavy boundary.
IIB23	29-41+ inches (74-104+cm). White (2.5 Y8/2) gravelly silt loam, pale yellow (2.5 Y 8/4) moist; common, medium, distinct mottles, brownish yellow (10 YR 6/6), yellowish brown (10 YR 5/8) moist; moderate, medium, subangular blocky structure; firm (moist), slightly sticky and slightly plastic (wet); few, thin silt flows in pores; no roots; common very fine and fine, and few medium discontinuous irregular pores; 30% gravels, 15% cobbles, 10% stones; acid (pH 5.2).

M-5

Classification: Andic Dystrochrept, coarse-silty over loamy-skeletal, mixed, frigid.

Location: Lincoln County, MT. NE¼ of NE¼ of Sec. 21, T33N, R32W.

Physiographic position: Hill slope, 4,360 ft. (1,329 m) elevation.

Topography: Slightly convex, 40% slope, N42^{o}E aspect.

Drainage: Moderately well drained, moderately rapid percolation rate, considered to have moderate drainage for this study.

Vegetation: Larix occidentalis, Pinus contorta, Pseudotsuga menziesii, Picea engelmannii, Thuja plicata, Alnus sinuata, Salix sp. Arnica cordifolia, Rubus parviflorus, Clintonia uniflora, Goodyera oblongifolia, Viola orbiculata, Linnaea borealis, Pachistima myrsinites, Vaccinium globulare, Pteridium aquilinium.

Parent material: Volcanic ash over glacial till.

Sampled by: C. Spitzner, September 9, 1980.

Remarks: All course fragments are subangular to subrounded; structure in the IIB2 horizon may be exhibiting weak platiness.

01&02 2-0 inches (5.1-0 cm)

B1 0-1 inches (0-2.5 cm). Yellow (10 YR 8/6) silt loam, dark yellowish brown (10 YR 4/6) moist; weak, medium, granular structure; soft (dry), very friable (moist), slightly sticky and slightly plastic (wet); many very fine, fine, and medium roots; many very fine, fine, and medium vesicular pores; acid (pH 5.14); clear, wavy boundary.

B21 1-7 inches (2.5 - 18 cm). Very pale brown (10 YR 7/4) silt loam, dark yellowish brown (10 YR 4/6) moist; weak, medium, granular structure; soft (dry) very friable (moist), slightly sticky and slightly plastic (wet); many very fine, fine, medium and coarse roots; many very fine, fine, and medium vesicular pores; 10% gravel; acid (pH 5.95); gradual, wavy boundary.

B22 7-14 inches (18-36 cm). Very pale brown (10 YR 7/4) silt loam, yellowish brown (10 YR 5/6) moist; weak, medium, granular structure; soft (dry), very friable (moist) slightly sticky and slightly plastic (wet); many very fine, fine, and medium, and common coarse roots; many very fine, fine, and medium vesicular pores; 10% gravel; acid (pH 5.70); abrupt, wavy boundary.

M-5 cont'd.

IIA2	14-17 inches (36-43 cm) White (2.5 Y 8/2) very gravelly loamy sand, pale yellow (2.5 Y 7/4) moist; moderate medium granular to weak fine subangular blocky structure; soft (dry), friable (moist), slightly sticky and slightly plastic (wet); many very fine and fine roots; common very fine and many fine discontinuous irregular pores; 60% gravel; acid (pH 5.36); clear, wavy boundary.
IIA&B	17-24 inches (43-61 cm). White (2.5 Y 8/2) very gravelly sandy loam, light gray (2.5 Y 7/2) moist; moderate, medium, subangular blocky structure; slightly hard (dry), firm (moist), slightly sticky and slightly plastic (wet); few, thin silt flows in pores; few very fine, fine, medium roots; few very fine, common fine discontinuous irregular pores; 55% gravel, 10% cobbles; acid (pH 5.18); gradual, wavy boundary.
IIB&A	24-36 inches (61-91 cm). White (2.5 Y 8/2) very gravelly silt loam, light gray (2.5 Y 7/2) moist; few, medium, distinct mottles, light yellowish brown (2.5 Y 6/4), light olive brown (2.5 Y 5/6) moist; moderate, medium, subangular blocky structure; slightly hard (dry), firm (moist), slightly sticky and slightly plastic (wet); few, moderately thick silt flows in pores and as bridges; few very fine and fine roots; common fine irregular discontinuous pores; 55% gravels, 15% cobbles; acid (pH 4.99); clear, wavy boundary.
IIB2	36-42+ inches (91-107+ cm). White (2.5 Y 8/2) very gravelly silt loam, pale yellow (2.5 Y 7/4) moist; common, coarse, distinct mottles, light yellowish brown (2.5 Y 6/4), light olive brown (2.5 Y 5/4) moist; moderate, coarse, subangular blocky structure; slightly hard (dry), firm (moist), sticky and plastic (wet); common, moderately thick silt flows on ped faces and in pores; no roots; few fine discontinuous irregular pores; 50% gravels, 10% cobbles; acid (pH 4.87).

M-6

Classification: Andic Dystrochrept, coarse-silty over loamy-skeletal, mixed, frigid.

Location: Lincoln County, MT. SE¼ of SE¼ of Sec. 16, T33N, R32W.

Physiographic position: Hill slope, 4,600 ft. (1,402 m) elevation.

Topography: Slightly convex, 39% slope, N16^{o}W aspect.

Drainage: Moderately well drained, moderately rapid percolation, considered to have moderate drainage for this study.

Vegetation: Larix occidentalis, Pinus contorta, Pseudotsuga menziesii, Pinus monticolor, Thuja plicata, Picea engelmannii, Tsuga heterophylla, Alnus sinuata, Salix sp., Arnica cordifolia, Viola orbiculata, Pachistima myrsinites, Linnaea borealis, Clintonia uniflora, Vaccinium globulare, Rubus parviflorus, Goodyera oblongifolia, Pyrola sp., Menziesia ferruginea Pteridium aquilinium.

Parent material: Volcanic ash over glacial till.

Sampled by: C. Spitzner, September 8, 1980.

Remarks: From the IIA2 horizon downward, coarse fragments are primarily subangular or subrounded; horizon separation in the glacial till is based heavily on structural changes.

O1&O2 1.5-0 inches (3.8-0 cm).

A2 0-0.5 inches (0-1.3 cm). Light gray (10 YR 7/1) silt loam, dark grayish brown (10 YR 4/2) moist; weak, medium, granular structure; soft (dry), very friable (moist), slightly sticky and slightly plastic (wet); many very fine and fine roots; many very fine, fine, and medium vesicular pores; acid (pH 4.92); abrupt, broken boundary.

B21 0.5-7 inches (1.3-18 cm). Very pale brown (10 YR 7/4) gravelly silt loam, dark yellowish brown (10 YR 4/4) moist; weak, medium, granular structure; soft (dry), very friable (moist), slightly sticky and slightly plastic (wet); many very fine, fine, and medium, and common coarse roots; many very fine, fine, and medium vesicular pores; 15% angular gravels; acidic (pH 5.56); gradual, wavy boundary.

B22 7-12 inches (18-30.5 cm). Very pale brown (10 YR 8/4) gravelly silt loam, yellowish brown (10 YR 5/4) moist; weak, medium, granular structure; soft (dry), very friable (moist), slightly sticky and slightly plastic (wet); many very fine, fine, and medium, and common coarse roots; many very fine, fine, and medium vesicular pores; 15% angular gravels; acid (pH 5.28); abrupt, wavy boundary.

M-6 cont'd.

IIA2 12-16 inches (30.5-41 cm). Pale yellow (2.5 Y 8/4) moist; very gravelly silt loam; weak, fine, subangular blocky structure; soft (dry), friable (moist), slightly sticky and slightly plastic (wet); common, thin silt films in pores; common very fine and fine, and few medium roots; many very fine and fine discontinuous irregular pores; 45% gravels; acid (pH 4.66) gradual, wavy boundary.

IIA&B 16-32 inches (41-81 cm). White (2.5 Y 8/2) very gravelly silt loam, pale yellow (2.5 Y 7/4) moist; common, medium, distinct mottles, pale yellow (2.5 Y 7/4), brownish yellow (10 YR 6/6) moist; weak, medium, subangular blocky structure; slightly hard (dry), friable (moist), slightly sticky and slightly plastic (wet); common, moderately thick silt flows in pores and as bridges between peds; few very fine and fine roots; many very fine and fine discontinuous irregular pores; 45% gravels, 5% cobbles, 5% stones; acid (pH 4.45); gradual, irregular boundary.

IIB2 32-48+ inches (81-122+ cm). Pale yellow (2.5 Y 8/4) cobbly silt loam, pale yellow (2.5 Y 7/4) moist; many, medium, distinct mottles, yellow (2.5 Y 7/6), brownish yellow (10 YR 6/8) moist; moderate, medium, subangular blocky structure; slightly hard (dry), firm (moist), slightly sticky and slightly plastic (wet); common, moderately thick silt flows as bridges between peds and in pores; few very fine and fine roots; many very fine and fine discontinuous irregular pores; 15% gravels, 20% cobbles, 10% stones; acid (pH 4.58).

IIB2 (Proximity to heavily weathered rocks)
32-48+ inches (81-122+ cm). Yellow (2.5 Y 8/6), yellow (10 YR 7/8) moist; common, medium, distinct mottles, brownish yellow (10 YR 6/8), yellowish brown (10 YR 5/8) moist.

M-7

Classification: Andic Dystrochrept, coarse-silty over loamy-skeletal, mixed, frigid.

Location: Lincoln County, MT. SE¼ of SE¼ of Sec. 16, T33N, R32W.

Physiographic position: Hill slope, 4,580 ft. (1,396 m) elevation.

Topography: Slightly concave, 40% slope, N25^{O}W aspect.

Drainage: Moderately well drained, moderate percolation, considered to have moderate drainage for this study.

Vegetation: Larix occidentalis, Pinus contorta, Pseudotsuga menziesii, Tsuga heterophylla, Pinus monticolor, Thuja plicata, Picea englemannii, Alnus sinuata, Salix sp., Linnaea borealis, Arnica cordifolia, Viola orbiculata, Goodyera oblongifolia, Vaccinium globulare, Pachistima myrsinites, Rubus parviflorus, Clintonia uniflora, Ribes sp., Menziesia ferruginea, Peteridium aquilinium.

Parent material: Volcanic ash over glacial till.

Sampled by: C. Spitzner and J. Collins, July 16, 1980.

Remarks: Coarse fragments are subangular and subrounded.

01&02 1-0 inches (2.5-0 cm).

A2 0-0.5 inches (0-1.3 cm). Light gray (10 YR 7/1) silt loam, grayish brown (10 YR 5/2) moist; weak, medium, granular structure; soft (dry), very friable (moist), slightly sticky and nonplastic (wet); many very fine, fine, and medium vesicular pores; acid (pH 4.32); abrupt, broken boundary.

B21irh 0.5-1.5 inches (1.3-3.8 cm). Yellowish brown (10 YR 5/4) silt loam, dark yellowish brown (10 YR 3/6) moist; weak, medium, granular structure; soft (dry), very friable (moist), slightly sticky and slightly plastic (wet); many very fine, fine, and medium vesicular pores; acid (pH 5.12); clear, broken boundary.

B22 1.5-12 inches (3.8-30.5 cm). Very pale brown (10 YR 7/4) silt loam, dark yellowish brown (10 YR 4/6) moist; weak, medium, granular structure; soft (dry), very friable (moist), slightly sticky and slightly plastic (wet); many very fine, fine, and medium, and common coarse roots; many very fine, fine and medium vesicular pores; 10% gravels; acid (pH 5.42); clear, wavy boundary.

IIA2 12-15 inches (30.5-38 cm). White (2.5 Y 8/2) very gravelly silt loam, Pale yellow (2.5 Y 7/4) moist; moderate, medium, subangular blocky structure; slightly hard (dry), friable (moist), slightly sticky and nonplastic (wet); common very fine and fine, and few medium roots; common very fine and few fine discontinuous irregular pores; 40% gravels; acid (pH 5.0); clear, wavy boundary.

M-7 cont'd.

IIA&B 15-24 inches (38-61 cm). White (2.5 Y 8/2) very gravelly silt loam, pale yellow (2.5 Y 7/4) moist; few, fine, faint mottles, light yellowish brown (2.5 Y 6/4), olive yellow (2.5 Y 6/6) moist; moderate, medium, subangular blocky structure; slightly hard (dry), firm (moist), slightly sticky and slightly plastic (wet); common very fine and few fine and coarse roots; many very fine and common fine discontinuous irregular pores; 35% gravels, 5% cobbles; acid (pH 4.96); diffuse, wavy boundary.

IIB21 24-31 inches (61-79 cm). White (2.5 Y 8/2) very gravelly silt loam, pale yellow (2.5 Y 7/4) moist; common, medium, faint mottles, pale yellow (2.5 Y 8/4), light yellowish brown (2.5 Y 6/4) moist; moderate, medium, subangular blocky structure, slightly hard (dry), firm (moist), slightly sticky and slightly plastic (wet); few, thin silt flows in pores and on ped faces; common very fine and few fine roots; many very fine and few fine discontinuous irregular pores; 40% gravels, 5% cobbles; acid (pH 5.17); gradual, wavy boundary.

IIB22 31-40+ inches (79-102+ cm). White (2.5 Y 8/2) very gravelly silt loam, yellow (2.5 Y 8/6) moist; discontinuous mottles on ped faces, light yellowish brown (2.5 Y 6/4), brownish yellow (10 YR 6/8) moist; moderate, coarse, subangular blocky structure; hard (dry), firm (moist), slightly sticky and slightly plastic (wet); common, moderately thick silt films in pores and on ped faces; few very fine and fine roots; common very fine and few fine discontinuous irregular pores; 40% gravels, 15% cobbles; acid (pH 5.03).

M-8

Classification: Andic Cryochrept, loamy-skeletal, mixed.

Location: Lincoln County, MT. SE¼ of SW¼ of Sec. 16, T33N, R32W.

Physiographic position: Hill slope, 4,640 ft. (1,414 m) elevation.

Topography: Slightly convex, 55% slope, N45°W aspect.

Drainage: Moderately well drained, moderately rapid percolation, considered to have moderate drainage for this study.

Vegetation: Larix occidentalis, Pinus contorta, Pseudotsuga menziesii, Tsuga heterophylla, Pinus monticolor, Thuja plicata, Picea engelmannii, Alnus sinuata, Salix sp., Linnaca borealis, Arnica cordifolia, Viola orbiculata, Goodyera oblongifolia, Vaccinium globulare, Pachistima myrsinites, Rubus parviflorus, Clintonia uniflora, Ribes sp., Menziesia ferruginea, Pteridium aquilinium.

Parent material: Volcanic ash over glacial till.

Sampled by: C. Spitzner and K. Newman, September 8, 1980.

Remarks: Coarse fragments are angular, subangular, and subrounded throughout; bedrock outcrops in the area; tree throw common.

01&02 3-0 inches (7.6-0 cm).

B21 0-8 inches (0-20 cm). Very pale brown (10 YR 7/4) stoney silt loam, dark yellowish brown (10 YR 3/6) moist; weak, medium granular structure; soft (dry), very friable (moist), slightly sticky and slightly plastic (wet); many very fine, fine, medium, and coarse roots; many very fine, fine, and medium vesicular pores; 20% stones, 10% cobbles, 10% gravels; acid (pH 5.47); gradual, wavy boundary.

B22 8-14 inches (20-36 cm). Very pale brown (10 YR 8/4) cobbly silt loam, yellowish brown (10 YR 5/8) moist; weak, medium, granular structure; soft (dry), very friable (moist), slightly sticky and slightly plastic (wet); many very fine, fine, and medium vesicular pores; 10% stones, 20% cobbles, 10% gravels; acid (pH 5.79); abrupt, wavy boundary.

IIA&B 14-18 inches (36-46 cm). White (2.5 Y 8/2) very gravelly silt loam, yellow (2.5 Y 7/6) moist; weak, fine, subangular blocky structure; soft (dry), friable (moist), slightly sticky and slightly plastic (wet); many very fine and fine, and common medium roots; many very fine, common fine, and few medium discontinuous tubular pores; 40% gravels, 20% cobbles; acid (pH 5.78); gradual, wavy boundary.

M-8 cont'd.

IIB&A 18-36 inches (46-91 cm). Pale yellow (2.5 Y 8/4) very gravelly silt loam, yellow (2.5 Y 7/6) moist; moderate, medium, subangular blocky structure; slightly hard (dry), firm (moist), slightly sticky and slightly plastic (wet); very few, thin silt films in pores; few very fine and fine roots; many very fine, fine, and medium discontinuous irregular pores; 40% gravels, 20% cobbles, 10% stones; acid (pH 5.75); gradual, wavy boundary.

IIB 36-43+ inches (91-109 cm). Pale yellow (2.5 Y 8/4) very gravelly sandy loam, yellow (2.5 Y 7/6) moist; weak, medium, subangular blocky structure; slightly hard (dry), firm (moist), slightly sticky and slightly plastic (wet); very few, thin silt films in pores; common very fine and fine roots; many very fine, fine, and medium discontinuous irregular pores; 40% gravels, 20% cobbles, 20% stones; acid (pH 5.53).

F-1

Classification: Andic Dystrochrept, coarse-loamy over loamy-skeletal, mixed, frigid.

Location: Lincoln County, MT. SW¼ of NE¼ of Sec. 25, T33N, R32W.

Physiographic position: Hill slope, 4,080 ft. (1,244 m) elevation.

Topography: Slightly convex, 51% slope, N38^{o}E aspect.

Drainage: Moderately well drained, rapid percolation, considered to have moderate drainage for this study.

Vegetation: Pinus contorta, Larix occidentalis, Thuja plicata, Abies grandis, Pseudotsuga menziesii, Pinus monticolor, Salix sp., Alnus sinuata, Tsuga heterophylla, Pachistima myrsinites, Arnica cordifolia, Viola orbiculata.

Parent material: Volcanic ash over thin glacial till.

Sampled by: C. Spitzner and G. Newman, August 22, 1980.

Remarks: Coarse fragments are angular, subangular, subrounded.

01&02 1.5-0 inches (3.8-0 cm).

B21 0-4 inches (0-10 cm). Very pale brown (10 YR 7/4) silt loam, brown to dark brown (7.5 YR 4/4) moist; weak, medium, granular structure; soft (dry), very friable (moist), slightly sticky and slightly plastic (wet); many very fine, fine, medium, and coarse roots; many very fine, fine, and medium vesicular pores; acid (pH 5.16); clear, wavy boundary.

B22 4-10 inches (10-25 cm). Very pale brown (10 YR 8/4) gravelly silt loam, brown (7.5 YR 5/4) moist; weak, medium, granular structure; soft (dry), very friable (moist), slightly sticky and slightly plastic (wet); many very fine, fine, and medium, and common coarse roots; many very fine, fine and medium vesicular pores; 25% gravels; acid (pH 5.35); clear, wavy boundary.

IIA2 10-15 inches (25-38 cm). Very pale brown (10 YR 8/3) very gravelly silt loam, light yellowish brown (10 YR 6/4) moist; moderate, fine, subangular blocky structure; soft (dry), friable (moist), non-sticky and slightly plastic; common very fine, fine, and medium, and few coarse roots; many very fine and fine, and common medium discontinuous irregular pores; 40% gravels, 25% cobbles, 5% stones; acid (pH 4.92); gradual, wavy boundary.

F-1 cont'd.

IIB&A	15-39 inches (38-99 cm). Very pale brown (10 YR 8/3) very gravelly silt loam, yellowish brown (10 YR 5/6) moist; strong, medium, subangular blocky structure; hard (dry), firm (moist), slightly sticky and slightly plastic (wet); few, thin silt films in pores; very few thin clay films in pores; common very fine and fine, and few medium roots; many very fine and fine, and common medium discontinuous irregular pores; 40% gravels, 25% cobbles, 5% stones; acid (pH 4.28); gradual, wavy boundary.
IIB2	39-48+ inches (99-122+cm). Very pale brown (10 YR 8/4) very gravelly silt loam, yellowish brown (10 YR 5/6) moist; strong, medium to coarse, subangular blocky structure; hard (dry), firm (moist), slightly sticky and slightly plastic (wet); few, thin silt flows in pores; few very fine and fine roots; many very fine and fine, and common medium discontinuous irregular pores; 40% gravels, 30% cobbles, 5% stones; acid (pH 4.51).

F-2

Classification: Andic Dystrochrept, coarse-loamy over loamy-skeletal, mixed, frigid.

Location: Lincoln County, MT. SW¼ of NE¼ of Sec. 25, T33N, R32W.

Physiographic position: Hill slope, 4,200 ft. (1,280 m) elevation.

Topography: Slightly convex, 53% slope, N34°E aspect.

Drainage: Moderately well drained, moderately rapid percolation, considered to have moderate drainage for this study.

Vegetation: Pseudotsuga menziesii, Larix occidentalis, Thuja plicata, Pinus contorta, Abies grandis, Tsuga heterophylla, Alnus sinuata, Salix sp., Acer glabrum, Picea engelmannii, Clintonia uniflora, Pachistima myrsinites, Rosa sp., Arnica cordifolia, Pyrola sp., Viola orbiculata, Rubus parviflorus, Goodyera oblongifolia, Vaccinium globulare.

Parent material: Volcanic ash over thin glacial till.

Sampled by: C. Spitzner, August 24, 1980.

Remarks: Coarse fragments are angular, subangular, and subrounded throughout.

O1&O2 3-0 inches (7.6-0 cm).

B21 0-4 inches (0-10 cm). Very pale brown (10 YR 7/4) silt loam, dark yellowish brown (10 YR 4/4) moist; weak, medium, granular structure; soft (dry), very friable (moist) slightly sticky and slightly plastic (wet); many very fine, fine, and medium, and few coarse roots; many very fine, fine and medium vesicular pores; 10% gravels, 5% cobbles; acid (pH 5.5); clear, wavy boundary.

B22 4-13 inches (10-33 cm). Very pale brown (10 YR 7/4) gravelly silt loam, dark yellowish brown (10 YR 4/6) moist; weak, medium, granular structure; soft (dry), very friable (moist), slightly sticky and slightly plastic (wet); many very fine, fine, and medium, and few coarse roots; many very fine, fine, and medium vesicular pores; 15% gravels, 5% cobbles; acid (pH 5.88); gradual, wavy boundary.

IIB&A 13-21 inches (33-53 cm). Very pale brown (10 YR 8/3) very gravelly sandy loam, yellow (10 YR 7/6) moist; moderate, fine, subangular blocky structure; slightly hard (dry), friable (moist), slightly sticky and nonplastic (wet); many very fine, common fine, and medium roots; many very fine, fine, and medium discontinuous irregular pores; 40% gravels, 30% cobbles, <5% stones; acid (pH 5.08); gradual, wavy boundary.

IIB2 21-44+ inches (53-112+cm). Very pale brown (10 YR 8/4) very gravelly silt loam, very pale brown (10 YR 7/4) moist; strong, fine to medium, subangular blocky structure; hard (dry), firm (moist), slightly sticky and slightly plastic (wet); very few, thin silt films in pore spaces; common very fine and fine, and few medium roots; many very fine, fine and medium discontinuous irregular pores; 40% gravels, 30% cobbles, <5% stones; acidic (pH 4.8).

F-3

Classification: Andic Cryochrept, coarse-loamy over loamy-skeletal, mixed.

Location: Lincoln County, MT. SW¼ of SW¼ of Sec. 23, T33N, R32W.

Physiographic position: Hill slope, 4,200 ft. (1,280 m) elevation.

Topography: Slightly convex, 53% slope, N2^{o}W aspect.

Drainage: Moderately well drained, rapid percolation, considered to have moderate drainage for this study.

Vegetation: Larix occidentalis, Pinus contorta, Thuja plicata, Picea engelmannii, Pseudotsuga menziesii, Salix sp., Alnus sinuata, Tsuga heterophylla, Goodyera oblongifolia, Epilobium angustifolium, Arnica cordifolia, Shepherdia canadensis, Menziesia ferruginea, Rubus parviflorus, Viola orbiculata, Vaccinium globulare, Chimaphila umbellata, Linnaea borealis, Spirea betulifolia, Ribes sp., Listera sp.

Parent material: Volcanic ash over very thin glacial till and bedrock (Wallace limestone).

Sampled by: C. Spitzner, August 27, 1980.

Remarks: Coarse fragments in the loess horizons are primarily rounded or subrounded.

01&02 1.5-0 inches (3.8-0 cm).

A2 0-1 inches (0-2.5 cm). White (10 YR 8/1) silt loam, dark grayish brown (10 YR 4/2) moist; weak, medium, granular structure; soft (dry), very friable (moist), slightly sticky and slightly plastic (wet); many very fine and fine, and common medium vesicular pores; acid (pH 4.79); abrupt, broken boundary.

B1 1-2 inches (2.5-5.1 cm). Very pale brown (10 YR 7/3) silt loam, brown (7.5 YR 5/4) moist; weak, medium, granular structure; soft (dry), very friable (moist), slightly sticky and slightly plastic (wet); many very fine, fine, and medium, and common coarse roots; many very fine, fine and medium vesicular pores; <5% gravels; acid (pH 4.87); abrupt, broken boundary.

B21 2-7 inches (5.1-18 cm). Very pale brown (10 YR 7/4) gravelly silt loam, dark yellowish brown (10 YR 4/6) moist; weak, medium, granular structure; soft (dry), very friable (moist), slightly sticky and slightly plastic (wet); many very fine, fine, medium, and coarse roots; many very fine, fine, and medium vesicular pores; 15% gravels, 15% cobbles; acid (pH 5.23); clear, wavy boundary.

F-3 cont'd.

B22	7-14 inches (18-36 cm). Very pale brown (10 YR 7/4) gravelly silt loam, yellowish brown (10 YR 5/8) moist; weak, medium, granular structure; soft (dry), very friable (moist), slightly sticky and slightly plastic (wet); many very fine and fine, and common medium roots; many very fine, fine, and medium vesicular pores; 15% gravels, 15% cobbles; acid (pH 5.57); abrupt, wavy boundary.
IIA2	14-23 inches (36-58 cm). White (2.5 Y 8/2) very gravelly sandy loam, light gray (2.5 Y 7/2) moist; weak, fine, granular to subangular blocky structure; slightly hard (dry), friable (moist), non-sticky and slightly plastic (wet); very few, thin silt flows in pores; common very fine and fine, and few medium roots; many very fine, fine, and medium discontinuous irregular pores; 35% angular, subangular, and rounded gravels, 15% angular, subangular, and rounded cobbles; acid (pH 5.5); abrupt, irregular boundary.
IIIC	23-38+ inches (58-97+ cm). White (2.5 Y 8/2), pale yellow (2.5 Y 7/4) moist; single grain; few very fine and fine roots; 95% rounded, angular, and subangular cobbles and stones.
IIA2 Fingers	23-35 inches (58-89 cm). Gravelly sandy loam; weak, fine, granular to subangular blocky structure; slightly hard (dry), friable (moist), non-sticky and slightly plastic (wet); common very fine and fine roots; many very fine, fine, and medium discontinuous irregular pores; 10% cobbles, 30% gravels; acid (pH 5.28).

F-4

Classification:	Andic Cryochrept, loamy-skeletal, mixed.
Location:	Lincoln County, MT. SE 1/4 of SW 1/4 of Sec. 23, T33N, R32W.
Physiographic position:	Hill slope, 4200 ft (1380 m) elevation.
Topography:	Slightly concave, 62% slope, N21°E aspect.
Drainage:	Well drained, very rapid percolation, considered to have rapid drainage for this study.
Vegetation:	*Larix occidentalis*, *Pinus contorta*, *Picea engelmannii*, *Tsuga heterophylla*, *Thuja plicata*, *Alnus sinuata*, *Pseudotsuga menziesii*, *Salix* sp., *epilobium angustifolium*, *Menziesia ferruginea*, *Goodyera oblongifolia*, *Rubus parviflorus*, *Pachistima myrsinites*, *Spirea betulifolia*, *Vaccinium globulare*, *Shepherdia canadensis*, *Ribes* sp., *Arnica cordifolia*, *Chimaphila umbellata*, *Pyrola* sp., *Clintonia uniflora*, *Viola orbiculata*.
Parent material:	Volcanic ash over Wallace limestone bedrock.
Sampled by:	C. Spitzner, August 26, 1981.
01-02	2-0 inches (5-0 cm)
A2	0-1 inches (0-2.5 cm). Light gray (10 YR 7/1) cobbly silt loam, dark grayish brown (10 YR 4/2) moist; weak, medium, granular structure; soft (dry), very friable (moist), slightly sticky and slightly plastic (wet); many very fine, fine, and medium roots; many very fine, fine, and medium vesicular pores; 20% angular cobbles, 5% angular gravels; acid (pH 3.8); abrupt, wavy boundary.
B21	1-13 inches (2.5-33 cm). Yellow (10 YR 7/6) cobbly silt loam, dark yellowish brown (10 YR 4/6) moist; moderate, medium, granular structure; soft (dry), very friable (moist), slightly sticky and slightly plastic (wet); many very fine, fine, medium, and coarse roots; many very fine, fine, and medium vesicular pores; 20% angular gravels, 30% angular cobbles; acid (pH 5.21); gradual, wavy boundary.
B22	13-21 inches (33-53 cm). Yellow (10 YR 7/6) cobbly silt loam, yellowish brown (10 YR 5/8) moist; moderate, medium, granular structure; soft (dry), very friable (moist), slightly sticky and slightly plastic (wet); many very fine, fine, and medium vesicular pores; 20% angular gravels, 30% angular cobbles; acid (pH 5.58); gradual, wavy boundary.
B3	21-30 inches (53-76 cm). Small pockets. Very pale brown (10 YR 7/4) silt loam, dark yellowish brown (10 YR 4/4) moist; weak, fine, granular structure; soft (dry), very friable (moist), slightly sticky and slightly plastic (wet); many very fine, common fine and few medium roots; many very fine and fine, and few medium vesicular pores; 90% angular cobbles and stones; acid (pH 5.8).
IICr	21-35+ inches (53-89+cm).

F-5

Classification: Andic Lithic Dystrochrept, loamy-skeletal, mixed, frigid.

Location: Lincoln County, MT. SE¼ of SW¼ of Sec. 23, T33N, R32W.

Physiographic position: Hill slope, 4,160 ft. (1,268 m) elevation.

Topography: Slightly concave, 57% slope, N14^{O}E aspect.

Drainage: Well drained, very rapid percolation, considered to have rapid drainage for this study.

Vegetation: Larix occidentalis, Pinus contorta, Picea engelmannii, Thuja plicata, Tsuga heterophylla, Pseudotsuga menziesii, Alnus sinuata, Salix sp., Epilobium angustifolium, Menziesia ferruginea, Goodyera oblongifolia, Rubus parviflorus, Pachistima myrsinites. Spirea betulifolia, Vaccinium globulare, Shepherdia canadensis, Ribes sp., Arnica cordifolia, Chimaphila umbellata, Pyrola sp., Clintonia uniflora, Pteridium aquilinium, Juniperus horizontalis, Viola orbiculata.

Parent material: Volcanic ash over thin glacial till and Wallace limestone.

Sampled by: C. Spitzner, August 26, 1980.

01&02 2.5-0 inches (6.4-0 cm).

A2 0-1 inches (0-2.5 cm). White (10 YR 8/1) sandy loam, grayish brown (10 YR 5/2) moist; weak, medium, granular structure; soft (dry), friable (moist), slightly sticky and nonplastic (wet); many very fine and fine, and common medium roots; many very fine, fine, and medium vesicular pores; 5% angular and subangular gravels; acid (pH 4.28); abrupt, wavy boundary.

B2 1-12 inches (2.5-30.5 cm). Very pale brown (10 YR 7/4) very cobbly silt loam, dark yellowish brown (10 YR 4/4) moist; weak, medium, granular structure; soft (dry), friable (moist), slightly sticky and slightly plastic; many very fine, fine, medium, and coarse roots; many very fine, fine, and medium vesicular pores; 20% angular and subangular gravels, 35% angular and subangular cobbles; acid (pH 5.68); clear, wavy boundary.

IIA&B 12-22 inches (30.5-56 cm.) White (2.5 Y 8/2) angular cobbly sandy loam, light yellowish brown (2.5 Y 6/4) moist; moderate, fine, granular to subangular blocky structure; slightly hard (dry), friable (moist), slightly sticky and slightly plastic; many very fine, fine, and medium, and common coarse roots; many very fine and fine, and few medium discontinuous irregular pores; 75% angular cobbles; acid (pH 5.84); abrupt, irregular boundary.

IIICr 22-24+ inches (56-61+cm). Wallace limestone, >90% angular cobbles and gravels; common very fine and fine roots; noncalcareous.

F-6

Classification: Andic Dystrochrept, loamy-skeletal, mixed, frigid.

Location: Lincoln County, MT. NE¼ of SW¼ of Sec. 23, T33N, R32W.

Physiographic position: High valley slope, 4,000 ft. (1,219 m) elevation.

Topography: Slightly convex, 53% slope, N45^{O}W aspect.

Drainage: Well drained, rapid percolation, considered to have rapid drainage for this study.

Vegetation: Larix occidentalis, Pinus contorta, Picea engelmannii, Tsuga heterophylla, Thuja plicata, Pseudotsuga menziesii, Pachistima myrsinites, Epilobium angustifolium, Goodyera oblongifolia, Chimaphila umbellata, Rubus parviflorus, Arnica cordifolia, Ribes sp., Viola orbiculata, Vaccinium globulare.

Parent material: Volcanic ash over thin glacial till.

Sampled by: C. Spitzner, August 8, 1980.

Remarks: Coarse fragments are primarily angular with a few weathered subangular fragments; smaller gravels are primarily rounded; tree throw common; inclusions in the IIB2 horizon are apparently from the weathering of large rock fragments.

01&02 1.5-0 inches (3.8-0 cm).

B21 0-4 inches (0-10 cm). Very pale brown (10 YR 7/3) cobbly silt loam, dark yellowish brown (10 YR 4/4) moist; weak, medium, granular structure; soft (dry), friable (moist), slightly sticky and slightly plastic (wet); many very fine, fine, and medium, and common coarse roots; many very fine, fine, and medium vesicular pores; 20% gravels, 30% cobbles; acid (pH 5.38); clear, wavy boundary.

B22 4-12 inches (10-30.5 cm). Very pale brown (10 YR 7/4) cobbly silt loam, dark yellowish brown (10 YR 4/6) moist; weak, medium, granular structure; soft (dry), friable (moist), slightly sticky and slightly plastic (wet); many very fine, fine, and medium, and common coarse roots, many very fine, fine, and medium vesicular pores; 20% gravels, 30% cobbles; acid (pH 5.5); abrupt, wavy boundary.

IIA2 12-16 inches (30.5-41 cm). White (2.5 Y 8/2) very gravelly loamy sand, light yellowish brown (2.5 Y 6/4) moist; weak, medium, granular structure; soft (dry), very friable (moist), non-sticky and nonplastic (wet); many very fine and fine, and common medium roots; common very fine and fine, and few medium discontinuous irregular pores; 35% cobbles, 45% gravels; acid (pH 5.47); gradual, irregular boundary.

F-6 cont'd.

IIB2	16-40+ inches (41-102+cm). White (2.5 Y 8/2) very gravelly sandy loam, light yellowish brown (2.5 Y 6/4) moist; moderate, coarse, subangular blocky structure; slightly hard (dry), very friable (moist), slightly sticky and slightly plastic (wet); common, moderately thick silt flows in pores; common very fine and fine, and few medium roots; common very fine and fine, and many medium discontinuous irregular pores; 30% cobbles, 15% stones, 40% gravels; acid (pH 5.44).
Inclusion A	White (10 YR 8/2) very gravelly sandy loam, very pale brown (10 YR 7/4) moist; acid (pH 5.19).
Inclusion B	Predominate, pale yellow (2.5 Y 8/4), very gravelly sandy loam, yellow (2.5 Y 7/6) moist; acid (pH 5.44).

F-7

Classification: Andic Cryochrept, loamy-skeletal, mixed.

Location: Lincoln County, MT. NE¼ of SE¼ of Sec. 16, T33N, R32W.

Physiographic position: Hill slope, 4,680 ft. (1,426 m) elevation.

Topography: Slightly concave, 43% slope, N58^{o}W aspect.

Drainage: Moderately well drained, rapid percolation, considered to have moderate drainage for this study.

Vegetation: Larix occidentalis, Pinus contorta, Pseudotsuga menziesii, Pinus monticolor, Thuja plicata, Picea engelmannii, Salix sp., Alnus sinuata, Tsuga heterophylla, Shepherdia canadensis, Rubus parviflorus, Pteridium aquilinium, Pachistima myrsinites, Viola orbiculata, Arnica cordifolia, Linnaea borealis, Vaccinium globulare, Goodyera oblongifolia, Chimaphila umbellata, Pyrola sp., Clintonia uniflora.

Parent material: Volcanic ash over thin glacial till.

Sampled by: C. Spitzner, September 9, 1980.

Remarks: Coarse fragments are mostly angular and subangular with a small percentage rounded; deeper, larger coarse fragments are more rounded.

01&02 1-0 inches (2.5-0 cm).

B21 0-11 inches (0-28 cm). Very pale brown (10 YR 7/4) very cobbly silt loam, dark yellowish brown (10 YR 4/6) moist; weak, medium, granular structure; soft (dry), very friable (moist), slightly sticky and slightly plastic (wet); many very fine, fine, medium, and coarse roots; many very fine, fine, and medium vesicular pores; 50% cobbles, 10% gravels, <5% stones; acid (pH 5.24); gradual, wavy boundary.

B22 11-15 inches (28-38 cm). Very pale brown (10 YR 7/4) very gravelly silt loam, dark yellowish brown (10 YR 4/6) moist; weak, medium, granular structure; soft (dry), very friable (moist), slightly sticky and slightly plastic (wet); many very fine, fine, medium and coarse roots; many very fine, fine, and medium vesicular pores; 40% gravels, 25% cobbles, <5% stones; acid (pH 5.35); abrupt, wavy boundary.

IIA2 15-17 inches (38-43 cm). White (2.5 Y 8/2) gravelly sandy loam, pale yellow (2.5 Y 7/4) moist; moderate, medium, granular to weak, fine, subangular blocky structure; soft (dry), friable (moist), slightly sticky and slightly plastic (wet); many very fine and fine, and common medium roots; many very fine and fine, and few medium discontinuous irregular pores; 45% gravels, 25% cobbles, 5% stones; acid (pH 5.42); clear, wavy boundary.

F-7 cont'd.

IIA&B 17-22 inches (43-56 cm). White (2.5 Y 8/2) very gravelly silt loam, light yellowish brown (2.5 Y 6/4) moist; weak, fine, subangular blocky structure; slightly hard (dry), friable (moist), slightly sticky and slightly plastic (wet); few, thin silt films in pores; many very fine and fine, and few medium roots; many very fine and fine discontinuous irregular pores; 40% gravels, 20% cobbles, 5% stones; acid (pH 5.14); gradual, wavy boundary.

IIB&A 22-29 inches (56-74 cm). White (2.5 Y 8/2) very gravelly silt loam, light yellowish brown (2.5 Y 6/4) moist; moderate, fine, subangular blocky structure; slightly hard (dry), firm (moist), slightly sticky and slightly plastic (wet); common, thin silt flows in pores; common very fine and fine roots; common very fine and many fine discontinuous irregular pores; 35% gravels, 25% cobbles, 5% stones; acid (pH 5.31); gradual, wavy boundary.

IIB 29-43+ inches (74-109+cm). White (2.5 Y 8/2) very cobbly silt loam, pale yellow (2.5 Y 7/4) moist; many medium, distinct mottles, yellowish brown (10 YR 5/6), dark yellowish brown (10 YR 3/4) moist; moderate, medium, subangular blocky structure, slightly hard (dry), firm (moist), slightly sticky and slightly plastic (wet); common, moderately thick silt flows in pores and as bridges between peds; few very fine and fine roots; few very fine and common fine discontinuous irregular pores; 30% gravels, 35% cobbles, 5% stones; acid (pH 5.86).

F-8

Classification: Andic Cryochrept, loamy-skeletal, mixed.

Location: Lincoln County, MT. SW¼ of SE¼ of Sec. 16, T33N, R32W.

Physiographic position: Hill slope, 4,640 ft. (1,414 m) elevation.

Topography: Slightly concave, 51% slope, N6^{o}E aspect.

Drainage: Well drained, very rapid percolation, considered to have rapid drainage for this study.

Vegetation: Larix occidentalis, Pinus contorta, Pseudotsuga menziesii, Pinus monticolor, Thuja plicata, Tsuga heterophylla, Picea engelmannii, Alnus sinuata, Clintonia uniflora, Arnica cordifolia, Menziesia ferruginea, Rubus parviflorus, Vaccinium globulare, Pteridium aquilinium, Linnaea borealis, Goodyera oblongifolia, Pyrola sp., Spirea betulifolia.

Parent material: Volcanic ash over thin glacial till and bedrock.

Sampled by: C. Spitzner, September 8, 1980.

Remarks: Coarse fragments mostly angular and subangular with some subrounded.

O1&O2 2-0 inches (5.1-0 cm).

A2 0-.5 inches (0-1.3 cm). White (10 YR 8/1) silt loam, light gray (10 YR 7/2) moist; weak, medium, granular structure; soft (dry), very friable (moist), slightly sticky and slightly plastic (wet); many very fine and fine roots; many very fine, fine, and medium vesicular pores; acid (pH 5.0); abrupt, broken boundary.

B21 0.5-12 inches (1.3-30.5 cm). Yellow (10 YR 7/6) gravelly silt loam, dark yellowish brown (10 YR 4/6) moist; weak, medium, granular structure; soft (dry), very friable (moist), slightly sticky and slightly plastic (wet); many very fine, fine, and medium, and common coarse roots; many very fine, fine, and medium vesicular pores; 25% gravels, 20% cobbles; acid (pH 5.08); gradual, wavy boundary.

B22 12-20 inches (30.5-51 cm). Yellow (10 YR 7/6) gravelly silt loam, yellowish brown (7.5 YR 5/6) moist; weak, medium, granular structure; soft (dry), very friable (moist), slightly sticky and slightly plastic (wet); many very fine, fine, and medium roots; many very fine, fine, and medium vesicular pores; 25% gravels, 15% cobbles; acid (pH 4.98); gradual, wavy boundary.

F-8 cont'd.

B-3	20-25 inches (51-64 cm). Very pale brown (10 YR 7/4) gravelly loamy sand, yellowish brown (10 YR 5/6) moist; weak, medium, granular structure; soft (dry), very friable (moist), non-sticky and slightly plastic (wet); common very fine, fine, and medium roots; many very fine, fine, and medium vesicular pores; 25% gravels, 15% cobbles; acid (pH 5.34); gradual, wavy boundary.
IIB&A	25-30+ inches (64-76+ cm). Pale yellow (2.5 Y 8/4) stoney sandy loam, brownish yellow (10 YR 6/6) moist; weak, fine, subangular blocky structure; soft (dry), friable (moist), slightly sticky and slightly plastic (wet); common very fine and fine roots; many very fine and fine vesicular and discontinuous irregular pores; 10% gravels, 25% cobbles, 50% stones; acid (pH 4.85).

APPENDIX 5

Measured Sample Tree Data

MEASURED SAMPLE TREE DATA

SITE CODE	TREE NUMBER	DBH (IN)	HEIGHT (FT)	DOMINANCE CLASS	AGE (YRS)	SAPWOOD WIDTH (IN)	RINGS IN SAPWOOD	RINGS/IN JUVENILE GROWTH	RINGS/IN RECENT GROWTH
S-1	1	6.6	66	D	60	.81	18	14	21
S-1	2	7.3	73	D	61	1.31	25	16	19
S-1	3	7.2	68	D	64	1.00	22	13	22
S-1	4	7.2	79	D	61	1.25	24	10	20
S-1	5	8.3	80	D	59	.88	18	9	20
S-1	6	7.5	68	D	62	1.06	16	15	15
S-1	7	7.7	77	CD	56	1.00	18	9	18
S-2	1	8.4	69	CD	60	.88	27	9	29
S-2	2	8.1	71	D	61	1.19	21	10	18
S-2	3	7.1	60	D	61	1.13	24	12	22
S-2	4	7.4	74	D	58	1.13	25	10	23
S-2	5	7.6	81	D	59	1.00	24	10	24
S-2	6	6.9	71	D	60	.88	25	9	30
S-2	7	8.0	80	D	61	1.13	23	10	19
S-3	1	11.3	100	D	64	1.38	18	8	14
S-3	2	7.4	76	D	60	1.13	26	14	23
S-3	3	8.2	79	D	65	.88	19	12	21
S-3	4	6.7	70	D	56	.88	22	9	26
S-3	5	7.2	69	D	60	1.13	25	12	23
S-3	6	6.9	70	CD	56	1.00	23	10	23
S-3	7	7.2	66	CD	56	.94	20	9	21
S-4	1	5.7	63	D	56	.69	19	12	25
S-4	2	9.0	90	D	58	1.13	19	10	17
S-4	3	7.3	79	D	63	1.00	23	12	23
S-4	4	8.2	76	D	62	1.00	18	13	18
S-4	5	6.7	74	CD	62	.94	23	14	24
S-4	6	7.1	73	CD	62	.88	24	11	26
S-4	7	8.1	81	D	58	.94	15	10	16
M-1	1	6.4	65	D	46	1.13	19	14	16
M-1	2	7.1	60	D	43	1.19	16	10	13
M-1	3	7.3	66	D	44	1.31	16	13	11
M-1	4	7.9	65	D	45	1.06	13	13	12
M-1	5	5.4	53	D	42	1.00	22	15	22
M-1	6	6.0	54	CD	44	.81	22	12	25
M-1	7	7.2	65	D	41	1.00	15	10	15
M-2	1	6.2	59	D	43	1.31	19	16	15
M-2	2	9.2	76	D	44	1.19	10	9	8
M-2	3	8.0	71	D	47	1.00	14	9	14
M-2	4	6.8	63	D	41	.81	11	13	14
M-2	5	7.0	62	D	47	1.25	22	8	19
M-2	6	7.3	65	D	44	1.25	15	10	11
M-2	7	7.5	65	D	45	1.13	14	11	13
M-3	1	6.0	52	CD	45	.94	17	14	19
M-3	2	5.9	56	D	44	1.06	15	16	14
M-3	3	6.1	62	D	41	1.00	17	14	16
M-3	4	8.7	64	D	46	1.06	14	13	13
M-3	5	7.0	59	D	42	1.13	16	13	15
M-3	6	6.8	61	CD	45	1.38	20	14	14
M-3	7	6.8	68	D	45	.81	10	14	13

MEASURED SAMPLE TREE DATA (CONTINUED)

M-4	2	7.2	66	CD	48	1.13	20	14	18
M-4	3	7.9	66	CD	50	.88	16	16	18
M-4	4	7.3	70	D	50	.88	19	16	21
M-4	5	6.3	61	CD	48	1.00	21	14	21
M-4	6	7.6	59	CD	48	1.06	18	13	17
M-4	7	7.2	66	CD	47	.88	15	13	17
M-5	1	8.0	78	CD	50	1.13	21	12	18
M-5	2	7.4	75	CD	51	1.00	22	14	22
M-5	3	8.9	74	D	49	.69	15	13	20
M-5	4	8.3	71	D	49	1.38	16	11	14
M-5	5	7.0	72	CD	48	1.13	18	14	16
M-5	6	7.6	66	D	48	1.19	18	12	15
M-5	7	7.8	76	D	50	1.00	18	13	18
M-6	1	5.3	51	CD	44	1.06	19	23	18
M-6	2	5.5	55	D	49	1.13	20	24	19
M-6	3	7.7	65	D	45	1.06	14	12	13
M-6	4	7.0	65	D	45	1.06	15	16	14
M-6	5	6.5	61	D	44	1.00	14	19	14
M-6	6	6.1	51	D	47	.94	15	16	16
M-6	7	6.3	55	D	41	1.13	17	15	16
M-7	1	5.5	47	D	47	1.19	20	18	17
M-7	2	6.6	58	D	52	.94	14	18	15
M-7	3	7.2	58	D	48	1.44	18	12	14
M-7	4	5.6	54	D	49	1.13	19	20	18
M-7	5	6.3	58	D	48	1.25	20	19	17
M-7	6	8.9	67	D	52	1.06	14	14	13
M-7	7	6.7	56	D	52	1.25	17	20	14
M-8	1	5.8	60	D	45	1.13	18	14	16
M-8	2	6.7	53	D	48	1.00	17	14	17
M-8	3	4.9	50	D	47	1.06	20	18	19
M-8	4	6.7	59	D	46	.69	14	14	18
M-8	5	5.2	48	D	45	1.00	19	19	19
M-8	6	8.2	61	D	47	.94	14	15	9
M-8	7	7.4	65	D	45	.88	14	16	15
F-1	1	8.4	79	D	62	1.13	24	9	23
F-1	2	7.9	73	D	57	.94	19	8	20
F-1	3	8.2	77	D	52	1.44	24	7	17
F-1	4	8.2	80	D	64	1.13	17	14	15
F-1	5	6.9	76	CD	63	.94	22	15	23
F-1	6	7.1	71	CD	53	.94	21	8	20
F-1	7	7.3	75	CD	59	.75	19	9	24
F-2	1	7.8	76	CD	56	1.06	20	10	19
F-2	2	6.8	70	D	49	.94	23	8	24
F-2	3	7.9	78	CD	56	1.06	19	11	18
F-2	4	7.0	76	D	55	.94	18	11	19
F-2	5	7.6	74	CD	57	1.06	18	18	17
F-2	6	8.2	74	D	60	1.13	21	12	19
F-2	7	9.3	79	D	57	1.13	15	9	13
F-3	1	7.3	61	D	49	.55	9	15	17

MEASURED SAMPLE TREE DATA (CONTINUED)

F-3	3	7.0	66	D	44	.94	11	14	12
F-3	4	7.3	69	D	45	.94	14	11	15
F-3	5	7.3	69	D	45	.94	16	13	17
F-3	6	6.4	50	D	47	1.06	17	15	15
F-3	7	5.3	49	D	46	1.00	20	19	20
F-4	1	6.7	78	D	46	.75	14	15	17
F-4	2	6.2	55	CD	45	1.13	17	15	16
F-4	3	5.5	55	SD	45	1.13	19	14	16
F-4	4	6.7	64	CD	46	.88	17	18	19
F-4	5	8.2	70	D	48	1.50	16	15	9
F-4	6	6.6	53	D	44	.50	7	17	10
F-4	7	5.4	52	CD	39	1.13	17	17	15
F-5	1	6.2	51	CD	49	1.06	15	18	14
F-5	2	8.7	76	D	41	.88	7	13	8
F-5	3	7.8	66	D	46	.94	13	14	14
F-5	4	8.4	80	D	42	1.06	13	11	12
F-5	5	6.7	65	CD	48	.94	18	17	19
F-5	6	6.9	68	CD	49	1.13	16	11	14
F-5	7	6.1	55	CD	46	1.25	20	12	15
F-6	1	7.2	58	CD	45	1.00	14	10	14
F-6	2	5.7	57	CD	48	.94	14	18	15
F-6	3	7.3	60	D	46	1.75	17	17	9
F-6	4	6.5	57	CD	46	1.19	15	16	13
F-6	5	6.1	58	CD	45	1.00	11	17	11
F-6	6	5.9	58	CD	45	1.19	16	19	13
F-6	7	5.2	49	CD	46	1.19	20	21	17
F-7	1	8.3	65	D	50	1.06	16	11	15
F-7	2	8.4	60	D	47	1.00	13	13	13
F-7	3	7.7	66	D	48	1.00	17	14	17
F-7	4	7.4	66	D	50	.88	13	12	14
F-7	5	8.7	70	D	44	1.13	17	9	16
F-7	6	7.9	63	D	42	1.13	14	7	13
F-7	7	6.2	62	D	48	1.13	20	18	18
F-8	1	7.8	70	D	51	1.13	16	12	15
F-8	2	7.0	65	D	49	1.31	14	18	10
F-8	3	6.9	53	D	47	1.00	17	16	17
F-8	4	7.9	84	D	50	1.00	14	11	14
F-8	5	8.1	78	D	51	1.38	16	18	12
F-8	6	6.9	64	CD	49	1.38	16	17	11
F-8	7	6.0	58	CD	48	.75	19	13	23

APPENDIX 6

Stocking of Sample Sites

Sample Site Stocking Data

Site	Stocking	Site	Stocking	Site	Stocking
S-1	1433	M-1	2392	F-1	1913
S-2	2152	M-2	2034	F-2	1675
S-3	1913	M-3	1315	F-3	1077
S-4	1913	M-4	1675	F-4	1077
		M-5	1315	F-5	1196
		M-6	1315	F-6	1077
		M-7	956	F-7	1436
		M-8	1196	F-8	1315

APPENDIX 7

Moisture Stress Measurement Data

MOISTURE STRESS MEASUREMENT DATA

SITE CODE	TREE NUMBER	STRESS (MEGA-PASCALS)	MONTH	DAY	TIME
S-1	2	1.896	8	12	1927
S-1	3	1.999	8	12	2016
S-1	4	1.034	8	14	635
S-2	1	1.655	8	12	2046
S-3	1	.896	8	14	651
S-3	2	1.062	8	14	701
S-3	3	.896	8	14	712
S-4	1	1.034	8	14	723
S-4	2	.896	8	14	730
S-4	3	.965	8	14	747
F-1	1	.793	8	14	810
F-1	2	1.069	8	14	819
F-1	3	.862	8	14	834
F-2	1	1.517	8	14	855
F-2	2	1.800	8	14	910
F-2	3	1.793	8	14	935
F-2	4	1.862	8	14	953
F-3	1	1.793	8	13	1026
F-8	1	1.896	8	14	745
F-8	2	1.379	8	14	9999
M-1	1	.552	8	13	802
M-1	2	.448	8	13	810
M-1	3	.483	8	13	820
M-2	1	.414	8	13	836
M-2	2	.517	8	13	855
M-2	3	.517	8	13	911
M-3	1	.621	8	13	930
M-3	2	1.310	8	13	945
M-3	3	1.586	8	13	1004

MOISTURE STRESS MEASUREMENT DATA
(CONTINUED)

SITE CODE	TREE NUMBER	STRESS (MEGA-PASCALS)	MONTH	DAY	TIME
M-7	7	2.758	8	14	1828
M-8	1	2.068	8	14	1800
M-8	2	2.413	8	14	1802
M-8	3	2.413	8	14	1804
M-8	4	2.551	8	14	1806
M-8	5	2.551	8	14	1806
M-8	6	2.723	8	14	1807
M-8	7	2.758	8	14	1808
M-8	8	2.723	8	14	1810
M-8	9	2.723	8	14	1811
M-8	10	2.586	8	14	1812
F-3	1	2.103	8	13	1910
F-3	2	2.137	8	13	1912
F-3	3	2.137	8	13	1913
F-3	4	2.068	8	13	1914
F-3	5	2.206	8	13	1916
F-3	6	2.275	8	13	1920
F-3	7	2.241	8	13	1924
F-4	1	2.241	8	13	1925
F-4	2	2.275	8	13	1926
F-4	3	2.137	8	13	1927
F-4	4	2.103	8	13	1928
F-4	5	2.206	8	13	1931
F-4	6	2.206	8	13	1933
F-4	7	2.206	8	13	1935
F-5	1	2.241	8	13	1940
F-5	2	2.186	8	13	1941
F-5	3	2.241	8	13	1942
F-5	4	2.241	8	13	1944
F-5	5	2.241	8	13	1945
F-5	6	2.241	8	13	1947
F-5	7	2.241	8	13	1948
F-6	1	1.862	8	13	1954
F-6	2	2.413	8	13	1956
F-6	3	2.448	8	13	1957
F-6	4	2.275	8	13	1958
F-6	5	2.344	8	13	2000
F-6	6	2.723	8	13	2002
F-6	7	2.689	8	13	2004
F-7	1	2.275	8	14	1918
F-7	2	2.241	8	14	1919
F-7	3	2.344	8	14	1921
F-7	4	2.137	8	14	1922
F-7	5	2.206	8	14	1923
F-7	6	2.206	8	14	1924
F-7	7	2.206	8	14	1925
F-8	1	1.965	8	14	1935
F-8	2	1.689	8	14	1936
F-8	3	1.896	8	14	1937
S-1	1	1.793	8	12	1912

APPENDIX 8

Bulk Density Measurements

Bulk Density Measurements

Site	Layer	(g/cc) Bulk Density
S-1	Andic	0.92
	Subsoil	1.53
S-2	Andic	0.71
	Subsoil	1.50
S-3	Andic	1.09
	Subsoil	1.80
S-4	Andic	0.99
	Subsoil	1.62
M-1	Andic	0.95
	Subsoil	1.50
M-2	Andic	0.89
	Subsoil	1.59
M-3	Andic	0.97
	Subsoil	1.64
M-4	Andic	0.86
	Subsoil	1.40
M-5	Andic	0.87
	Subsoil	1.69
M-6	Andic	0.78
	Subsoil	1.62
M-7	Andic	0.76
	Subsoil	1.33
M-8	Andic	0.84
	Subsoil	1.22

Site	Layer	(g/cc) Bulk Density
F-1	Andic	1.09
	Subsoil	1.49
F-2	Andic	0.97
	Subsoil	1.50
F-3	Andic	0.99
	Subsoil	1.71
F-4	Andic	0.60
	Subsoil	1.56
F-5	Andic	0.88
	Subsoil	1.65
F-6	Andic	0.85
	Subsoil	1.51
F-7	Andic	0.71
	Subsoil	1.64
F-8	Andic	0.90
	Subsoil	1.41

APPENDIX 9

Particle Size Analysis

Particle Size Analysis

Site	Drainage	% Sand	% Silt	% Clay	Soil Texture	Horizon
S-1	Slow	22.4	50.0	27.6	Silt Loam	II A2
		20.4	42.0	37.6	Clay Loam	II A+B
S-3	Slow	30.4	44.0	25.6	Loam	II A2
		28.0	42.4	29.6	Clay Loam	II B+A
S-4	Slow	30.4	42.0	27.6	Loam	II A2
		30.4	38.0	31.6	Clay Loam	II A+B
M-2	Moderate	46.4	40.0	13.6	Loam	II A2
		42.8	43.6	13.6	Loam	II A+B
M-5	Moderate	38.8	45.6	15.6	Loam	II A2
		32.8	49.6	17.6	Loam	II A+B
M-6	Moderate	24.8	57.6	17.6	Silt Loam	II A2
		26.8	53.6	19.6	Silt Loam	II A+B
F-5	Rapid	38.8	39.6	21.6	Loam	II A+B
F-6	Rapid	48.8	37.6	17.6	Loam	II A2
		42.8	43.6	13.6	Loam	II B2
F-8	Rapid	34.8	47.6	17.6	Loam	II B+A
		46.8	37.6	15.6	Loam	II B2

APPENDIX 10

Original Soil Analysis Data

SOIL IONIC CONTENT BY SAMPLE SITE

SAMPLE NUMBER	SITE CODE	HORIZON DESIG	CA	CU	FE	K	MG	MN	NA	ZN	TOTAL N	PO4	NO3 (PPM)	$H^{+} \times 10^{-6}$	HORIZON THICKNESS (INCHES)	PERCENT COARSE FRAGMENTS
			MICROGRAMS/GRAM													
1	S-1	B21	800	.9	4.0	120	46	10.0	20	.3	587	263.2	4.5	1.950	0-1.5	10
2	S-1	B22	590	.9	4.0	75	55	6.3	26	.4	878	51.6	3.8	1.585	1.5-7	10
3	S-1	II B21	540	1.6	1.0	25	80	2.5	15	.5	193	1.6	2.7	6.617	7-14	50
4	S-1	II B22	760	2.1	2.5	50	128	3.8	16	.5	217	3.1	2.7	7.762	14-26	50
5	S-1	II B23	1150	1.6	5.0	75	225	5.0	20	.5	192	9.9	2.0	6.166	26-40+	25

SAMPLE NUMBER	SITE CODE	HORIZON DESIG	CA	CU	FE	K	MG	MN	NA	ZN	TOTAL N	PO4	NO3 (PPM)	$H^{+} \times 10^{-6}$	HORIZON THICKNESS (INCHES)	PERCENT COARSE FRAGMENTS
			MICROGRAMS/GRAM													
6	S-2	B21	990	1.5	5.0	170	61	5.0	28	.4	956	79.0	3.8	3.715	0.5-7	20
7	S-2	B22	900	1.5	4.0	170	54	2.5	28	.4	785	26.0	4.5	1.620	7-12	20
8	S-2	II A2	590	1.5	1.0	45	58	1.3	22	.4	224	5.1	3.8	5.623	12-15	50
9	S-2	II B21	550	1.9	1.0	30	61	1.3	17	.5	139	1.5	3.8	4.467	15-18	70
10	S-2	II B22	510	2.1	1.0	45	56	2.5	15	.4	133	2.2	3.8	6.457	18-34	70
11	S-2	III B2	1340	1.8	4.0	95	228	2.5	23	.1	231	1.0	1.7	6.210	34-40+	20

SAMPLE NUMBER	SITE CODE	HORIZON DESIG	CA	CU	FE	K	MG	MN	NA	ZN	TOTAL N	PO4	NO3 (PPM)	$H^{+} \times 10^{-6}$	HORIZON THICKNESS (INCHES)	PERCENT COARSE FRAGMENTS
			MICROGRAMS/GRAM													
12	S-3	B21	575	1.4	4.0	95	50	12.5	17	.4	643	120.8	3.8	2.734	0-7	20
13	S-3	B22	975	1.9	4.0	110	40	3.8	22	.4	653	58.6	3.8	1.230	7-12	15
14	S-3	II A+B	490	2.1	1.0	30	66	2.0	13	.4	172	0.1	2.0	2.138	12-19	45
15	S-3	II B+A	525	2.9	1.0	30	80	3.8	22	.4	172	0.0	2.7	10.471	16-31	55
16	S-3	II B2	890	2.5	2.5	70	150	3.8	18	.3	185	4.5	1.4	6.026	31-40+	45

SPECIAL HORIZON CODES

II A2* = TONGUES OF THE II A2 MATERIAL
II B2** = MATERIAL COLORED BY WEATHERING OF ROCK BUT AT A DISTANCE FROM THE ROCK
II B2*** = MATERIAL COLORED BY WEATHERING OF ROCK AND ADJACENT TO THE ROCK
*^ = SHALLOW INCLUSIONS
**^ = DEEP INCLUSIONS

SOIL IONIC CONTENT BY SAMPLE SITE CONTINUED

SAMPLE NUMBER	SITE CODE	HORIZON DESIG	CA	CU	FE	K	MG	MN	NA	ZN	TOTAL N	PO4	NO3 (PPM)	$H^+ \times 10^{-6}$	HORIZON THICKNESS (INCHES)	PERCENT COARSE FRAGMENTS
			MICROGRAMS/GRAM													
17	S-4	B21	760	1.5	5.0	195	59	13.0	17	.4	934	159.1	2.3	2.512	0-3	15
18	S-4	B22	800	1.0	5.0	163	65	9.0	16	.3	876	165.3	2.3	3.225	3-9	15
19	S-4	B3	325	2.1	1.0	63	39	3.0	11	.4	294	32.5	2.3	9.120	9-14	35
20	S-4	II A+B	625	2.1	1.0	38	79	3.0	19	.4	189	0.3	2.7	6.761	14-20	55
21	S-4	II B+A	675	2.4	1.0	45	109	3.8	14	.4	195	2.6	2.0	7.762	20-31	50
22	S-4	II B2	950	1.8	4.0	95	198	4.5	18	.3	220	6.9	1.2	12.023	31-41+	50

SAMPLE NUMBER	SITE CODE	HORIZON DESIG	CA	CU	FE	K	MG	MN	NA	ZN	TOTAL N	PO4	NO3 (PPM)	$H^+ \times 10^{-6}$	HORIZON THICKNESS (INCHES)	PERCENT COARSE FRAGMENTS
			MICROGRAMS/GRAM													
23	M-1	A2	560	2.0	2.5	45	60	5.0	22	1.5	423	45.9	2.0	48.978	0-1.5	10
24	M-1	B21	510	2.0	6.0	100	31	17.0	30	.9	952	21.9	2.0	12.023	1.5-7	35
25	M-1	B22	350	3.0	4.0	105	18	2.5	25	.5	465	13.4	2.0	8.710	7-12	45
26	M-1	II A21	400	3.1	1.0	30	20	2.5	14	.5	115	5.4	2.0	19.953	12-18	50
27	M-1	II A22	510	3.1	2.5	25	36	2.5	13	.6	107	3.2	2.3	20.417	18-33	80
28	M-1	II B+A	1225	3.1	2.5	45	86	4.5	16	.5	189	0.3	1.7	15.596	33-40+	75

SAMPLE NUMBER	SITE CODE	HORIZON DESIG	CA	CU	FE	K	MG	MN	NA	ZN	TOTAL N	PO4	NO3 (PPM)	$H^+ \times 10^{-6}$	HORIZON THICKNESS (INCHES)	PERCENT COARSE FRAGMENTS
			MICROGRAMS/GRAM													
29	M-2	A2	1125	3.0	4.0	68	55	27.0	25	1.1	827	73.1	5.3	13.183	0-0.5	0
30	M-2	B21	900	2.0	5.0	120	45	15.5	23	.6	933	48.1	2.7	4.898	0.5-6	30
31	M-2	B22	700	1.8	4.0	105	39	2.0	26	.5	648	4.0	2.7	8.710	6-12	25
32	M-2	II A2	910	2.3	4.0	25	29	1.3	22	.5	155	5.4	2.3	3.090	12-19	65
33	M-2	II A+B	1090	1.6	2.5	30	31	3.0	18	.5	141	3.2	2.7	4.467	19-27	65
34	M-2	II B+A	1190	2.3	5.0	50	39	3.0	19	.4	155	2.6	2.0	0.562	27-40+	55

SPECIAL HORIZON CODES

II A2* = TONGUES OF THE II A2 MATERIAL
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** = SHALLOW INCLUSIONS
*** = DEEP INCLUSIONS

SOIL IONIC CONTENT BY SAMPLE SITE CONTINUED

SAMPLE NUMBER	SITE CODE	HORIZON DESIG	CA	CU	FE	K	MG	MN	NA	ZN	TOTAL N	PO4	NO3 (PPM)	$H^+ \times 10^{-6}$	HORIZON THICKNESS (INCHES)	PERCENT COARSE FRAGMENTS
			MICROGRAMS/GRAM													
35	M-3	A2	400	2.3	6.0	100	40	27.0	22	1.4	496	50.4	4.5	97.724	0-0.5	0
36	M-3	B2	410	1.9	4.0	120	21	11.3	24	.4	722	3.8	2.7	15.849	0.5-9	10
37	M-3	B3	300	2.0	1.0	50	24	0.5	19	.3	178	11.7	2.0	6.913	9-11	10
38	M-3	II A2	400	2.8	1.0	25	24	0.5	17	.4	83	4.9	2.3	6.915	11-12	25
39	M-3	II A2*	540	3.0	2.5	25	49	2.5	21	.5	157	4.9	2.0	15.136	24-34	20
40	M-3	II A+B	360	2.8	1.0	20	31	0.5	19	.4	104	4.9	2.3	7.943	12-19	35
41	M-3	II B+A	625	2.1	1.0	25	64	0.9	15	.6	88	4.1	3.2	9.333	19-31	65
42	M-3	III C	933	2.2	1.8	55	106	3.8	25	.5	36	2.6	3.8	4.074	31-40+	45

SAMPLE NUMBER	SITE CODE	HORIZON DESIG	CA	CU	FE	K	MG	MN	NA	ZN	TOTAL N	PO4	NO3 (PPM)	$H^+ \times 10^{-6}$	HORIZON THICKNESS (INCHES)	PERCENT COARSE FRAGMENTS
			MICROGRAMS/GRAM													
43	M-4	A2	620	1.6	1.0	120	80	67.5	33	1.1	692	195.2	3.8	19.055	0-1	0
44	M-4	B21IR	805	1.5	4.0	253	71	46.5	35	.5	882	549.2	3.2	5.012	1-2	0
45	M-4	B22	745	1.3	1.0	142	35	9.0	39	.4	456	48.4	2.7	1.585	2-5	10
46	M-4	B23	788	1.3	1.0	142	43	4.4	37	.5	626	151.4	2.3	1.047	5-8.5	10
47	M-4	B3	600	1.4	1.0	155	31	2.5	34	.4	428	61.0	2.7	1.047	8.5-12	20
48	M-4	II A2	570	1.9	1.0	34	68	0.9	28	.5	119	13.1	2.3	1.660	12-15	35
49	M-4	II B21T	775	1.6	1.0	25	84	0.5	35	.4	148	1.7	2.3	2.918	16-19	60
50	M-4	II B22	1075	1.6	1.0	30	90	1.3	35	.5	168	1.1	1.2	5.012	19-29	50
51	M-4	II B23	1000	1.9	1.0	50	154	2.0	33	.4	157	1.1	3.2	6.310	29-41+	0

SAMPLE NUMBER	SITE CODE	HORIZON DESIG	CA	CU	FE	K	MG	MN	NA	ZN	TOTAL N	PO4	NO3 (PPM)	$H^+ \times 10^{-6}$	HORIZON THICKNESS (INCHES)	PERCENT COARSE FRAGMENTS
			MICROGRAMS/GRAM													
52	M-5	B1	990	.8	5.0	205	66	85.5	41	.5	847	306.6	4.5	7.244	0-1	0
53	M-5	B21	1300	1.0	2.5	95	36	3.0	41	.4	757	4.7	4.5	1.122	1-7	10
54	M-5	B22	690	1.4	1.0	100	34	2.0	49	.3	582	10.1	4.5	1.995	7-14	10
55	M-5	II A2	490	1.6	1.0	30	53	1.3	13	.1	146	12.5	5.2	4.365	14-17	60
56	M-5	II A+B	440	1.9	1.0	25	54	0.5	12	.3	119	3.5	4.5	6.607	17-24	55
57	M-5	II B+A	490	1.5	1.0	30	65	1.3	12	.4	112	4.1	3.2	10.233	24-36	70
58	M-5	II B2	975	1.6	4.0	55	91	2.5	15	.1	139	1.1	2.0	13.490	36-42+	60

SPECIAL HORIZON CODES

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** = SHALLOW INCLUSIONS
*** = DEEP INCLUSIONS

SOIL IONIC CONTENT BY SAMPLE SITE CONTINUED

SAMPLE NUMBER	SITE CODE	HORIZON DESIG	CA	CU	FE	K	MG	MN	NA	ZN	TOTAL N	PO4	NO3 (PPM)	$H^+ \times 10^{-6}$	HORIZON THICKNESS (INCHES)	PERCENT COARSE FRAGMENTS
			MICROGRAMS/GRAM													
59	M-6	A2	790	1.6	5.0	145	105	40.5	20	1.0	916	300.0	4.5	12.023	0-0.5	0
60	M-6	B21	300	1.0	4.0	225	35	11.3	21	.3	1264	3.5	2.7	2.754	0.5-7	15
61	M-6	B22	210	1.6	4.0	105	19	3.8	19	.3	839	9.5	3.2	5.249	7-12	15
62	M-6	II A2	210	1.8	1.0	30	21	0.5	12	.1	132	39.4	2.7	21.876	12-16	45
63	M-6	II A+B	240	2.0	1.0	20	25	0.5	12	.4	119	16.7	2.3	35.481	16-32	55
64	M-6	II B2**	540	2.5	1.0	38	61	8.0	13	.3	171	37.0	2.0	26.303	32-48+	45
65	M-6	II B2***	810	1.5	1.0	38	94	3.0	12	.3	165	27.9	2.3	20.417	32-48+	0

SAMPLE NUMBER	SITE CODE	HORIZON DESIG	CA	CU	FE	K	MG	MN	NA	ZN	TOTAL N	PO4	NO3 (PPM)	$H^+ \times 10^{-6}$	HORIZON THICKNESS (INCHES)	PERCENT COARSE FRAGMENTS
			MICROGRAMS/GRAM													
66	M-7	A2	1100	1.4	10.0	220	121	129.5	24	1.3	1439	377.7	6.2	47.863	0-0.5	0
67	M-7	B21IR	600	.9	5.0	220	43	23.9	17	.1	1130	342.1	3.2	7.586	0.5-1.5	0
68	M-7	B22	560	.3	2.5	145	50	3.0	23	.1	907	13.7	3.2	3.802	1.5-12	10
69	M-7	II A2	510	1.1	1.0	45	53	0.5	13	.3	207	77.4	3.2	10.000	12-15	40
70	M-7	II A+B	510	1.4	1.0	30	61	0.5	12	.1	159	26.1	3.2	10.965	15-24	40
71	M-7	II B21	675	1.6	2.5	30	80	1.3	12	.4	143	20.2	3.2	6.761	24-31	45
72	M-7	II B22	775	1.5	2.5	45	103	2.0	12	.1	171	36.8	2.0	9.333	31-40+	55

SAMPLE NUMBER	SITE CODE	HORIZON DESIG	CA	CU	FE	K	MG	MN	NA	ZN	TOTAL N	PO4	NO3 (PPM)	$H^+ \times 10^{-6}$	HORIZON THICKNESS (INCHES)	PERCENT COARSE FRAGMENTS
			MICROGRAMS/GRAM													
73	M-8	B21	1700	1.0	5.0	195	48	12.0	19	.1	1135	27.9	3.2	3.388	0-8	40
74	M-8	B22	790	1.5	4.0	163	34	5.5	18	.1	703	18.1	3.8	1.622	8-14	40
75	M-8	II A+B	625	1.8	6.0	50	29	2.5	13	.3	176	27.0	2.7	1.660	14-18	60
76	M-8	II B+A	740	2.1	6.0	25	56	0.5	11	.1	105	14.3	2.7	1.778	18-36	70
77	M-8	II B2	990	1.5	6.0	25	81	2.0	12	.4	139	18.1	3.2	2.951	36-43+	80

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SOIL IONIC CONTENT BY SAMPLE SITE CONTINUED

SAMPLE NUMBER	SITE CODE	HORIZON DESIG	CA	CU	FE	K	MG	MN	NA	ZN	TOTAL N	PO4	NO3 (PPM)	H^{+} X 10^{-5}	HORIZON THICKNESS (INCHES)	PERCENT COARSE FRAGMENTS
			MICROGRAMS/GRAM													
78	F-1	B21	910	.6	5.0	233	58	23.0	16	.1	911	227.7	3.8	6.918	0-4	0
79	F-1	B22	610	1.6	2.5	175	44	4.5	17	.1	609	57.5	3.2	4.467	4-10	25
80	F-1	II A2	900	1.0	1.0	200	71	1.3	12	.1	206	10.1	2.3	12.023	10-15	25
81	F-1	II B+A	250	1.4	1.0	55	74	3.0	11	.1	175	2.4	2.0	52.481	15-39	70
82	F-1	II B2	250	1.5	1.0	50	133	0.5	13	.1	172	0.4	1.7	30.903	39-48+	75

SAMPLE NUMBER	SITE CODE	HORIZON DESIG	CA	CU	FE	K	MG	MN	NA	ZN	TOTAL N	PO4	NO3 (PPM)	H^{+} X 10^{-6}	HORIZON THICKNESS (INCHES)	PERCENT COARSE FRAGMENTS
			MICROGRAMS/GRAM													
83	F-2	B21	1075	1.5	5.0	230	79	10.5	14	.3	790	76.5	2.3	3.162	0-4	15
84	F-2	B22	750	1.3	4.0	195	73	2.5	16	.3	664	32.1	2.7	1.318	4-13	20
85	F-2	II B+A	425	1.1	1.0	95	71	0.5	12	.1	213	9.9	2.3	8.318	13-21	75
86	F-2	II B2	540	2.0	1.0	63	84	0.5	13	.3	133	3.6	2.0	15.849	21-44+	75

SAMPLE NUMBER	SITE CODE	HORIZON DESIG	CA	CU	FE	K	MG	MN	NA	ZN	TOTAL N	PO4	NO3 (PPM)	H^{+} X 10^{-5}	HORIZON THICKNESS (INCHES)	PERCENT COARSE FRAGMENTS
			MICROGRAMS/GRAM													
87	F-3	A2	660	1.6	5.0	75	44	50.0	13	.6	452	42.7	3.8	16.218	0-1	0
88	F-3	B1	650	1.4	5.0	105	29	17.5	13	.4	535	378.7	2.3	13.490	1-2	5
89	F-3	B21	800	1.9	4.0	113	30	5.0	15	.1	615	39.4	2.7	5.888	2-7	30
90	F-3	B22	590	1.4	4.0	105	24	1.3	17	.3	419	5.1	3.2	2.692	7-14	30
91	F-3	II A2	725	1.9	1.0	30	49	0.5	10	.1	105	4.3	2.3	3.162	14-23	50
92	F-3	II A2*	325	2.0	1.0	30	49	1.3	11	.3	119	3.8	2.3	5.248	23-32	40

SPECIAL HORIZON CODES

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SOIL IONIC CONTENT BY SAMPLE SITE CONTINUED

SAMPLE NUMBER	SITE CODE	HORIZON DESIG	CA	CU	FE	K	MG	MN	NA	ZN	TOTAL N	PO4	NO3 (PPM)	H^{+} X 10^{-5}	HORIZON THICKNESS (INCHES)	PERCENT COARSE FRAGMENTS
			MICROGRAMS/GRAM													
93	F-4	A2	810	1.5	7.5	120	54	25.0	22	.8	1090	165.1	2.0	58.439	0-1	25
94	F-4	B21	1140	.9	5.0	120	40	7.5	21	.1	897	28.2	3.2	6.165	1-13	50
95	F-4	B22	1350	1.0	4.0	105	35	3.0	26	.1	676	1.5	3.2	2.530	13-21	60
96	F-4	B3	2250	1.5	1.0	113	59	1.5	16	.5	350	16.3	2.7	1.585	21-30+	90

SAMPLE NUMBER	SITE CODE	HORIZON DESIG	CA	CU	FE	K	MG	MN	NA	ZN	TOTAL N	PO4	NO3 (PPM)	H^{+} X 10^{-6}	HORIZON THICKNESS (INCHES)	PERCENT COARSE FRAGMENTS
			MICROGRAMS/GRAM													
97	F-5	A2	450	1.5	4.0	138	69	85.5	15	.9	743	101.1	4.5	52.491	0-1	5
98	F-5	B2	1240	1.4	6.0	230	45	10.5	13	.3	794	151.2	4.5	2.069	1-12	55
99	F-5	II A+B	950	1.6	4.0	50	45	3.0	11	.3	276	22.7	3.8	1.445	12-22	75

SAMPLE NUMBER	SITE CODE	HORIZON DESIG	CA	CU	FE	K	MG	MN	NA	ZN	TOTAL N	PO4	NO3 (PPM)	H^{+} X 10^{-6}	HORIZON THICKNESS (INCHES)	PERCENT COARSE FRAGMENTS
			MICROGRAMS/GRAM													
100	F-6	B21	860	1.5	5.0	150	36	8.8	15	.5	757	32.1	2.7	4.169	0-4	50
101	F-6	B22	650	1.5	4.0	125	26	1.3	17	.4	606	5.1	2.0	3.162	4-12	50
102	F-6	II A2	910	1.3	1.0	25	58	0.5	11	.4	172	7.9	2.0	3.388	12-16	80
103	F-6	II B1	790	2.0	1.0	25	76	0.5	11	.3	139	6.5	3.2	3.631	16-40+	85
104	F-6	**	1075	1.5	2.5	30	101	2.0	12	.1	150	3.8	1.7	6.457	16-40	0
105	F-6	***	960	1.0	1.0	30	73	0.5	12	.1	237	11.2	1.7	7.244	16-40	0

SPECIAL HORIZON CODES

II A2* = TONGUES OF THE II A2 MATERIAL
II B2** = MATERIAL COLORED BY WEATHERING OF ROCK BUT AT A DISTANCE FROM THE ROCK
II B2*** = MATERIAL COLORED BY WEATHERING OF ROCK AND ADJACENT TO THE ROCK
** = SHALLOW INCLUSIONS
*** = DEEP INCLUSIONS

SOIL IONIC CONTENT BY SAMPLE SITE CONTINUED

SAMPLE NUMBER	SITE CODE	HORIZON DESIG	CA	CU	FE	K	MG	MN	NA	ZN	TOTAL N	PO4	NO3 (PPM)	$H^{+} \times 10^{-6}$	HORIZON THICKNESS (INCHES)	PERCENT COARSE FRAGMENTS
			MICROGRAMS/GRAM													
106	F-7	B21	1410	1.5	6.0	163	61	7.0	20	.3	1266	10.6	2.0	5.754	0-11	65
107	F-7	B22	490	1.1	5.0	163	21	0.5	14	.1	407	22.2	2.3	4.467	11-15	70
108	F-7	II A2	460	1.8	1.0	45	34	0.5	11	.3	175	20.3	2.7	3.802	15-17	75
109	F-7	II A+B	600	1.5	1.0	30	73	0.5	12	.4	143	16.7	2.3	7.244	17-22	65
110	F-7	II B+A	860	1.8	1.0	25	90	2.5	11	.3	144	5.7	2.0	4.898	22-29	65
111	F-7	II B2	1460	1.6	4.0	30	135	2.0	11	.1	161	4.6	2.0	1.380	29-43+	70

SAMPLE NUMBER	SITE CODE	HORIZON DESIG	CA	CU	FE	K	MG	MN	NA	ZN	TOTAL N	PO4	NO3 (PPM)	$H^{+} \times 10^{-6}$	HORIZON THICKNESS (INCHES)	PERCENT COARSE FRAGMENTS
			MICROGRAMS/GRAM													
112	F-8	A2	960	1.0	2.5	80	90	29.5	15	.9	898	64.4	3.8	10.000	0-0.5	0
113	F-8	B21	610	1.0	10.0	100	85	12.5	14	.3	959	23.9	2.3	8.318	0.5-12	45
114	F-8	B22	410	1.0	6.0	70	44	2.0	15	.1	598	41.5	1.7	10.471	12-20	40
115	F-8	II B+A	1290	1.1	4.0	38	121	5.0	13	.1	361	13.4	1.7	4.571	20-25	40
116	F-8	II B2	490	1.3	5.0	75	46	0.5	14	.3	344	56.2	2.0	14.125	25-30+	85

SPECIAL HORIZON CODES

II A2* = TONGUES OF THE II A2 MATERIAL
II B2** = MATERIAL COLORED BY WEATHERING OF ROCK BUT AT A DISTANCE FROM THE ROCK
II B2*** = MATERIAL COLORED BY WEATHERING OF ROCK AND ADJACENT TO THE ROCK
** = SHALLOW INCLUSIONS
*** = DEEP INCLUSIONS

APPENDIX 11

Nutrient Content of Xylem Sap

NUTRIENT CONTENT OF XYLEM SAP

SITE CODE	CA	CU	FE	K	MG	MN	NA	ZN	PO4	TOTAL NITROGEN
	MILLIGRAMS/LITER									
S-1	2.8	.63	.250	33.8	2.00	.30	2.38	.450	.547	94.5
S-1	1.5	.38	.050	29.0	1.28	.30	1.00	.125	.547	84.0
S-1	2.2	.88	.125	31.0	1.38	.38	2.50	.125	.367	66.5
S-2	4.5	.38	.125	82.5	1.88	.20	.95	.200	.360	35.0
S-2	1.5	.30	.050	13.0	.63	.25	1.25	.125	.073	84.0
S-3	2.5	1.25	.125	33.0	1.65	.30	5.00	.550	.560	66.5
S-3	3.0	.70	.125	34.0	2.06	.45	1.25	.550	.420	66.5
S-3	3.5	.75	.125	30.0	2.13	.30	2.00	.700	.747	56.0
S-4	3.5	.75	.050	36.3	1.75	.25	2.20	.950	.847	52.5
S-4	3.5	.75	.050	34.8	2.06	.30	1.20	.500	.720	84.0
S-4	2.5	.80	.050	33.5	1.65	.25	1.50	.750	.460	80.5
M-1	3.0	.50	.250	32.0	1.90	.30	1.70	.250	.720	56.0
M-1	2.5	.25	.125	27.4	1.25	.25	.50	.125	.353	70.0
M-1	4.0	.38	.380	35.0	2.25	.63	1.00	.250	.673	70.0
M-2	2.5	.75	.125	29.5	1.25	.38	2.75	.125	.300	84.0
M-2	3.5	.50	.125	28.0	1.75	.38	1.00	.125	.520	45.5
M-2	2.2	.38	.125	29.8	1.31	.25	1.00	.200	.420	45.5
M-3	2.0	.55	.250	27.8	1.44	.25	1.05	.125	.613	38.5
M-3	3.0	.50	.125	27.3	2.23	.63	.50	.125	.407	45.5
M-3	2.0	.75	.250	24.8	1.19	.30	1.00	.125	.467	35.0
F-1	2.0	.75	.050	28.5	1.13	.20	1.95	.630	.267	122.5
F-1	2.0	.75	.050	23.5	1.13	.25	1.75	.500	.153	70.0
F-1	3.0	.75	.050	21.0	1.38	.50	1.38	.380	.293	56.0
F-2	3.5	.88	.050	19.5	1.69	.50	2.05	.750	.613	66.5
F-2	3.0	.75	.200	31.5	1.90	.50	1.50	.250	.807	101.5
F-2	3.0	.70	.250	16.5	1.69	.50	1.25	.380	.540	59.5
F-2	1.2	.70	.125	17.5	.81	.38	.75	.380	.200	105.0
F-3	1.5	.50	.125	27.0	1.06	.45	.05	.125	.387	87.5
F-8	3.0	.50	.250	20.3	8.00	.50	.88	.125	.413	45.5
F-8	2.0	.63	.250	15.0	.88	.20	2.00	.200	.340	112.0

APPENDIX 12

Calculations Used in Data Manipulations

Calculations used in data manipulations.

A. Determination of equivalent weights

$$\frac{\text{atomic wt of ion}}{\text{valence of ion}} = 1 \text{ equivalent weight of the ion}$$

1 milliequivalent weight = 1 equivalent weight expressed in mg

Ca = 40.04/2	= 20.02 mg/meq
Cu = 63.54/2	= 31.77 mg/meq
Fe = 55.847/2.5	= 22.34 mg/meq
K = 39.102/1	= 39.10 mg/meq
Mg = 24.305/2	= 12.15 mg/meq
Mn = 54.938/2	= 27.47 mg/meq
Na = 22.9898/1	= 22.99 mg/meq
Zn = 65.37/2	= 32.69 mg/meq
PO_4 = (30.9738 + (4 x 15.9994))/3	= 31.66 mg/meq

B. Conversion from micrograms/gram to meq/100 grams

(micrograms/gram)/1000 = mg/g

mg/g x 100 = mg/100 grams

(mg/100 grams)/(mg/meq) = meq/100 grams

C. Determination of sapwood area : basal area ratio.

diameter inside bark = (DBH x 0.87428) + 0.09492

basal area = $(DIB/2)^2 \times \pi$

heartwood area = $((DIB - 2(\text{sapwood thickness}))/2)^2 \times \pi$

sapwood area = basal area - heartwood area

$$\frac{\text{sapwood area}}{\text{basal area}} = \text{ratio}$$

D. Determination of coarse fragment volume

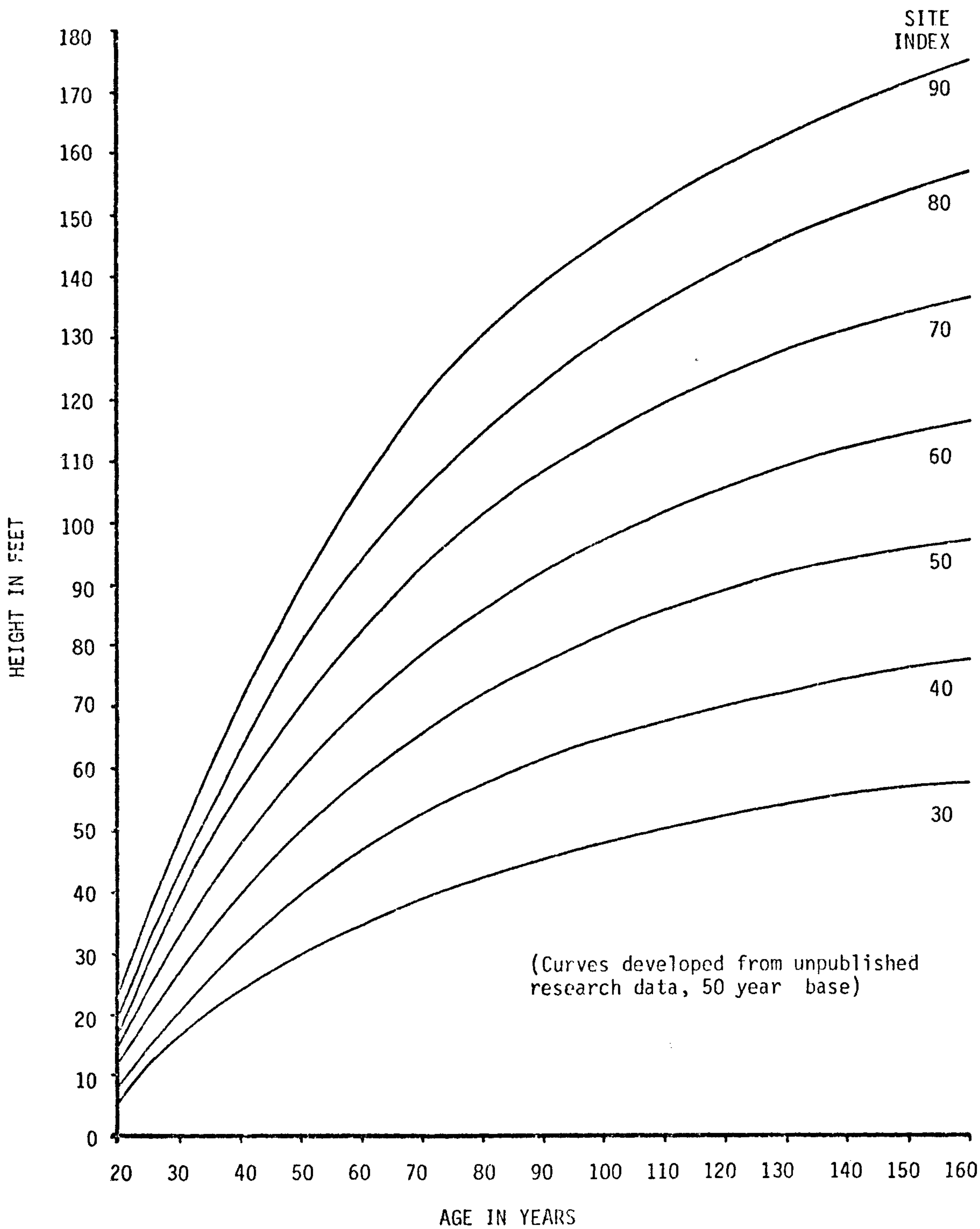
estimated % coarse fragments x soil volume = coarse fragment volume

APPENDIX 13

Site Index Curves for Western Larch

(From: The Forest Science Laboratory, U.S.D.A.
Forest Service, Missoula, Montana)

Site Index Curves for Western Larch (Average height of dominant trees)



APPENDIX 14

1. Soil Nutrient Concentration (micrograms/gram).
2. Soil Nutrient Availability per Square Meter (milliequivalents).
3. Soil Nutrient Availability per Hectare (kilograms).

1. Soil Nutrient Concentration (micrograms/gram).

SOIL NUTRIENT CONCENTRATION (MICROGRAMS/GRAM)

SITE	LAYER	CA	CU	FE	K	MG	MN	NA	ZN	PO4	NO3 (PPM)
		MICROGRAMS/GRAM									
S-1	ANDIC	635.00	0.90	4.00	84.64	53.07	7.09	24.71	0.38	96.94	4.0
S-1	SUBSOIL	878.79	1.78	3.24	55.30	158.97	4.03	17.48	0.50	5.67	2.4
S-2	ANDIC	950.87	1.50	4.57	170.00	57.96	3.91	29.00	0.40	55.96	4.1
S-2	SUBSOIL	757.86	1.94	1.64	54.11	93.61	2.24	17.68	0.35	2.19	3.4
S-3	ANDIC	800.00	1.61	4.00	102.50	45.83	8.87	19.08	0.40	94.97	3.8
S-3	SUBSOIL	634.62	2.60	1.48	42.86	99.50	3.41	18.79	0.37	1.47	2.1
S-4	ANDIC	621.79	1.50	3.57	134.14	54.43	7.57	14.43	0.35	116.54	2.3
S-4	SUBSOIL	773.00	2.09	2.20	63.32	137.40	3.89	16.80	0.36	3.77	1.8
M-1	ANDIC	449.58	2.42	4.73	95.21	29.21	9.46	26.92	0.31	21.35	2.0
M-1	SUBSOIL	655.18	3.10	2.18	31.07	45.07	3.00	13.96	0.58	2.95	2.1
M-2	ANDIC	809.38	1.94	4.46	111.17	42.42	9.23	24.58	0.57	27.26	2.9
M-2	SUBSOIL	1031.43	2.10	4.04	38.04	34.21	2.58	19.46	0.45	3.47	2.3
M-3	ANDIC	405.91	1.94	3.55	106.35	22.41	10.05	23.00	0.43	11.22	2.7
M-3	SUBSOIL	648.86	2.32	1.25	33.10	67.69	1.69	19.14	0.51	3.86	3.1
M-4	ANDIC	709.83	1.37	1.25	153.21	42.92	13.76	36.12	0.50	136.08	2.7
M-4	SUBSOIL	943.28	1.77	1.00	38.31	112.93	1.45	33.21	0.45	2.92	2.3
M-5	ANDIC	972.86	1.19	1.93	105.36	37.14	8.39	45.00	0.36	28.96	4.5
M-5	SUBSOIL	531.43	1.63	1.64	34.11	66.54	1.36	12.75	0.28	4.21	3.6
M-6	ANDIC	232.92	1.28	4.04	171.67	31.25	9.39	20.13	0.33	18.35	3.0
M-6	SUBSOIL	234.00	1.96	1.00	22.00	24.20	0.50	12.00	0.34	21.24	2.4
M-7	ANDIC	335.93	0.83	3.02	154.38	52.38	10.00	22.54	0.15	56.23	3.3
M-7	SUBSOIL	633.37	1.45	1.86	36.43	78.93	1.19	12.11	0.20	33.56	2.8
M-8	ANDIC	1310.00	1.21	4.57	181.29	42.00	9.21	18.57	0.10	23.70	3.5
M-8	SUBSOIL	784.48	1.90	6.00	29.45	58.31	1.14	11.52	0.20	16.97	2.3
F-1	ANDIC	730.00	1.20	3.90	200.20	49.60	11.90	16.60	0.10	125.58	3.4
F-1	SUBSOIL	335.63	1.37	1.00	72.59	67.58	2.18	11.61	0.10	2.94	2.0
F-2	ANDIC	930.00	1.36	4.31	205.77	74.95	4.96	15.38	0.30	45.79	2.6
F-2	SUBSOIL	510.32	1.77	1.00	71.26	80.65	0.50	12.74	0.25	5.37	2.1
F-3	ANDIC	674.29	1.59	4.14	105.71	27.93	7.83	15.71	0.26	46.72	3.0
F-3	SUBSOIL	725.00	1.90	1.00	30.00	49.00	0.50	10.00	0.10	4.30	2.3
F-4	ANDIC	1518.00	1.13	3.62	113.90	44.33	5.08	20.87	0.24	22.07	3.0
F-4	SUBSOIL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
F-5	ANDIC	1174.17	1.41	5.83	222.33	47.00	16.75	13.17	0.35	147.03	4.5
F-5	SUBSOIL	950.00	1.60	4.00	50.00	45.00	3.00	11.00	0.30	22.70	3.8
F-6	ANDIC	720.00	1.50	4.33	133.33	29.33	3.80	16.33	0.43	14.10	2.2
F-6	SUBSOIL	907.14	1.90	1.00	25.00	73.43	0.50	11.00	0.31	6.70	3.0
F-7	ANDIC	1164.67	1.39	5.73	163.00	50.33	5.27	18.40	0.25	13.69	2.1
F-7	SUBSOIL	1035.00	1.65	2.50	29.82	105.46	1.75	11.18	0.22	8.16	2.1
F-8	ANDIC	539.75	1.00	8.21	37.50	68.72	8.73	14.43	0.24	31.95	2.1
F-8	SUBSOIL	890.00	1.20	4.50	56.50	83.50	2.75	13.50	0.20	34.80	1.8

2. Soil Nutrient Availability per Square Meter (milliequivalents).

SOIL NUTRIENT AVAILABILITY PER SQUARE METER (MILLIEQUIVALENTS)

SITE	LAYER	CA	CU	FE	K	MG	MN	NA	ZN	PO4	TOTAL CATIONS	NO3 (PPM)
		MILLIEQUIVALENTS/SQUARE METER										
S-1	ANDIC	5189.	5.	29.	355.	715.	42.	175.	2.	501.	6508.	3.9
S-1	SUBSOIL	56294.	72.	186.	1814.	16776.	188.	975.	20.	230.	76305.	2.4
S-2	ANDIC	9851.	10.	42.	902.	989.	30.	253.	3.	367.	12076.	4.1
S-2	SUBSOIL	40383.	65.	78.	1477.	8213.	87.	821.	11.	74.	51129.	3.4
S-3	ANDIC	13276.	17.	60.	871.	1253.	107.	275.	4.	997.	15859.	3.8
S-3	SUBSOIL	40593.	105.	85.	1403.	10482.	159.	1046.	14.	59.	53873.	2.1
S-4	ANDIC	10934.	17.	56.	1208.	1576.	97.	221.	4.	1295.	14109.	2.3
S-4	SUBSOIL	39720.	68.	101.	1665.	11631.	146.	752.	11.	122.	54032.	1.8
M-1	ANDIC	6502.	22.	61.	705.	697.	100.	339.	7.	195.	8425.	2.0
M-1	SUBSOIL	35445.	104.	104.	847.	3956.	117.	648.	19.	99.	41223.	2.1
M-2	ANDIC	10967.	17.	54.	771.	946.	91.	289.	5.	234.	13137.	2.8
M-2	SUBSOIL	51649.	75.	204.	1100.	3184.	106.	958.	16.	124.	67273.	2.3
M-3	ANDIC	5495.	17.	43.	738.	500.	99.	272.	4.	96.	7161.	2.7
M-3	SUBSOIL	39152.	88.	68.	1023.	6729.	74.	1096.	19.	147.	48139.	3.1
M-4	ANDIC	9293.	11.	15.	1027.	927.	131.	411.	4.	1127.	11815.	2.7
M-4	SUBSOIL	48589.	57.	46.	1011.	9575.	55.	1489.	14.	92.	60821.	2.2
M-5	ANDIC	15034.	12.	27.	834.	946.	95.	605.	3.	283.	17550.	4.5
M-5	SUBSOIL	34907.	62.	83.	1048.	6581.	59.	667.	10.	160.	43413.	3.6
M-6	ANDIC	3360.	10.	43.	1044.	612.	81.	209.	2.	138.	5356.	3.0
M-6	SUBSOIL	9619.	51.	37.	463.	1638.	15.	430.	9.	552.	12253.	2.4
M-7	ANDIC	6779.	6.	31.	915.	998.	84.	227.	1.	411.	9040.	3.3
M-7	SUBSOIL	31589.	43.	79.	881.	6144.	41.	495.	6.	1003.	39274.	2.8
M-8	ANDIC	19546.	11.	61.	1385.	1032.	100.	241.	1.	224.	22377.	3.5
M-8	SUBSOIL	35214.	54.	241.	654.	4312.	37.	450.	6.	482.	40963.	2.8
F-1	ANDIC	10605.	10.	48.	1417.	1130.	120.	200.	1.	1098.	13021.	3.4
F-1	SUBSOIL	24102.	62.	64.	2682.	10365.	114.	727.	4.	131.	38114.	2.0
F-2	ANDIC	13599.	14.	62.	1586.	1973.	58.	214.	3.	463.	17605.	2.6
F-2	SUBSOIL	30107.	66.	53.	2153.	7838.	22.	655.	9.	201.	40892.	2.1
F-3	ANDIC	11856.	18.	65.	952.	809.	100.	240.	3.	520.	14042.	3.0
F-3	SUBSOIL	14156.	23.	18.	300.	1576.	7.	170.	1.	53.	16250.	2.3
F-4	ANDIC	59331.	27.	84.	1966.	2752.	97.	563.	7.	432.	64624.	3.0
F-4	SUBSOIL	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0
F-5	ANDIC	15731.	12.	70.	1525.	1037.	164.	154.	3.	1246.	18692.	4.5
F-5	SUBSOIL	19887.	21.	75.	535.	1552.	46.	201.	4.	301.	22318.	3.8
F-5	ANDIC	9319.	12.	50.	883.	626.	36.	184.	3.	115.	11108.	2.2
F-6	SUBSOIL	43296.	64.	43.	687.	6439.	20.	513.	10.	227.	51118.	3.0
F-7	ANDIC	15737.	12.	69.	1128.	1121.	52.	217.	2.	117.	18335.	2.1
F-7	SUBSOIL	63212.	60.	131.	889.	10141.	74.	568.	8.	301.	75656.	2.1
F-8	ANDIC	12303.	14.	168.	1022.	2586.	145.	286.	3.	461.	16526.	2.1
F-8	SUBSOIL	15921.	14.	72.	517.	2461.	36.	210.	2.	394.	19232.	1.9

3. Soil Nutrient Availability per Hectare (kilograms).

SOIL NUTRIENT AVAILABILITY PER HECTARE (KILOGRAMS)

SITE	LAYER	CA	CU	FE	K	MG	MN	NA	ZN	PO4	TOTAL N
		KILOGRAMS/HECTARE									
S-1	ANDIC	934.8	1.3	5.9	124.6	78.1	10.4	36.4	0.6	142.7	[illegible]
S-1	SUBSOIL	7199.2	13.6	27.6	456.6	1325.4	32.7	139.3	3.9	49.8	1552.0
S-2	ANDIC	2523.9	3.9	12.4	444.5	154.5	11.3	73.2	1.0	168.3	2376.5
S-2	SUBSOIL	4091.9	8.6	10.1	292.0	573.4	10.3	87.9	1.3	9.3	841.4
S-3	ANDIC	2044.3	4.1	10.0	259.2	113.5	21.1	48.5	1.0	229.7	1625.7
S-3	SUBSOIL	4157.7	16.6	9.8	283.9	653.0	21.8	119.2	2.4	20.3	1138.2
S-4	ANDIC	2237.6	4.9	13.5	503.2	188.7	20.5	50.7	1.2	436.6	2526.3
S-4	SUBSOIL	3257.9	8.9	9.2	265.2	575.1	16.4	71.5	1.5	15.5	862.4
M-1	ANDIC	1212.7	5.6	10.2	199.4	96.6	21.1	63.7	2.6	72.1	1547.4
M-1	SUBSOIL	2020.3	9.6	6.0	93.9	132.8	9.3	43.7	1.8	10.1	[illegible]
M-2	ANDIC	1982.0	4.9	10.0	245.9	102.3	28.2	56.6	1.5	82.3	[illegible]
M-2	SUBSOIL	4319.7	8.3	16.0	150.5	135.4	10.2	77.0	1.8	13.7	597.6
M-3	ANDIC	1394.1	7.0	14.7	360.5	95.1	51.8	78.3	2.5	79.3	[illegible]
M-3	SUBSOIL	3824.6	14.4	7.7	202.9	396.8	10.5	119.1	3.0	23.4	451.2
M-4	ANDIC	2194.8	4.6	3.8	461.3	171.2	93.0	112.6	2.1	501.1	1903.5
M-4	SUBSOIL	[illegible]	13.4	7.4	[illegible]	915.9	11.9	243.9	3.2	19.5	[illegible]
M-5	ANDIC	[illegible]	5.3	17.6	795.2	255.3	233.1	225.9	2.2	832.7	[illegible]
M-5	SUBSOIL	2475.8	6.8	7.2	144.8	278.3	3.8	53.3	1.1	17.6	[illegible]
M-6	ANDIC	860.8	3.2	10.1	403.6	104.2	34.9	46.5	1.1	154.5	2525.6
M-6	SUBSOIL	901.1	7.6	3.9	86.4	93.1	1.9	46.4	1.3	55.1	472.0
M-7	ANDIC	4534.9	6.0	36.4	986.5	473.2	410.0	119.4	4.2	1257.6	[illegible]
M-7	SUBSOIL	3361.1	7.4	9.1	182.7	391.5	5.6	61.8	1.0	171.3	[illegible]
M-8	ANDIC	2075.8	2.0	7.4	293.7	67.6	14.6	30.2	0.2	35.0	1510.7
M-8	SUBSOIL	1977.7	5.1	15.6	77.5	143.2	2.9	30.1	0.5	45.2	[illegible]
F-1	ANDIC	1112.7	2.2	5.4	310.0	77.3	14.5	27.4	0.2	159.9	1111.8
F-1	SUBSOIL	2171.4	6.5	5.0	476.0	415.7	10.4	53.1	0.5	21.2	315.7
F-2	ANDIC	1925.4	3.1	9.9	473.4	173.3	10.3	36.1	0.7	99.4	1615.8
F-2	SUBSOIL	1506.9	5.2	3.0	210.4	239.1	1.5	37.6	0.7	15.9	433.7
F-3	ANDIC	2540.6	6.0	16.9	362.4	125.5	94.0	56.1	1.4	193.2	1839.9
F-3	SUBSOIL	1417.0	3.7	2.0	58.5	95.8	1.0	19.5	0.2	8.4	226.2
F-4	ANDIC	3169.8	3.1	13.1	300.0	119.1	29.4	55.7	1.0	168.2	2171.7
F-4	SUBSOIL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F-5	ANDIC	1462.5	1.9	7.4	282.2	63.7	28.8	17.4	0.5	127.6	1028.0
F-5	SUBSOIL	995.4	1.7	4.2	52.4	47.1	3.1	11.5	0.3	23.8	269.2
F-6	ANDIC	1025.5	2.1	6.2	188.9	41.9	5.9	22.6	0.6	21.7	931.9
F-6	SUBSOIL	1570.0	3.2	1.7	42.2	122.7	0.8	13.6	0.5	11.4	244.7
F-7	ANDIC	6209.7	6.7	27.1	740.8	268.6	30.4	89.6	1.3	50.7	5567.9
F-7	SUBSOIL	3965.2	6.1	9.0	109.2	388.3	6.5	41.5	0.9	30.3	563.3
F-8	ANDIC	2253.6	3.5	23.4	298.2	257.6	48.6	51.1	1.4	141.9	2905.0
F-8	SUBSOIL	1517.6	1.5	5.6	61.0	142.4	5.5	17.7	0.2	29.5	480.3

APPENDIX 15

Means and Standard Deviations of Soil Data

Means and Standard Deviations of Soil Nutrient Concentrations
(Micrograms/Gram, Parts per Million for Nitrate)

Drainage Classification A

	Andic Layer				Subsoil Layer			
Drainage Class	Category	Mean	Standard Deviation	Standard Error	Category	Mean	Standard Deviation	Standard Error
Slow	Ca	674	176	71.9	Ca	730	91.4	37.3
	Cu	1.5	0.58	0.24	Cu	2.2	0.60	0.24
	Fe	4.0	0.63	0.26	Fe	2.1	0.63	0.26
	K	123	34.6	14.1	K	47.2	12.4	5.1
	Mg	48.8	10.4	4.2	Mg	102	40.9	16.7
	Mn	7.8	2.2	0.9	Mn	3.0	1.1	0.44
	Na	22.6	5.1	2.1	Na	16.1	2.6	1.0
	Zn	0.42	0.22	0.09	Zn	0.39	0.13	0.54
	PO_4	73.7	35.2	14.4	PO_4	8.3	12.5	5.1
	NO_3	3.3	0.9	0.4	NO_3	2.4	0.58	0.24
Moderate	Ca	763	345	130	Ca	685	285	108
	Cu	1.5	0.33	0.12	Cu	1.9	0.23	0.09
	Fe	3.4	1.3	0.12	Fe	2.3	2.0	0.75
	K	148	40.7	15.4	K	37.9	15.8	6.0
	Mg	41.9	16.3	6.2	Mg	63.5	29.4	11.1
	Mn	9.3	2.6	0.98	Mn	1.3	0.7	2.9
	Na	26.1	10.6	4.0	Na	17.3	7.8	2.9
	Zn	0.37	0.15	0.06	Zn	0.35	0.12	0.04
	PO_4	73.7	35.2	14.4	PO_4	8.3	7.5	2.8
	NO_3	3.1	0.68	0.26	NO_3	2.7	0.54	0.20
Rapid	Ca	834	269	110	Ca	779	258	105
	Cu	1.3	0.22	0.09	Cu	1.6	0.28	0.12
	Fe	5.4	1.6	0.66	Fe	2.3	1.6	0.65
	K	152	53.0	21.6	K	44.0	18.9	7.7
	Mg	45.5	15.2	6.2	Mg	74.0	23.4	9.5
	Mn	9.0	4.7	1.9	Mn	1.8	1.1	0.44
	Na	15.8	1.8	0.74	Na	11.4	1.2	0.48
	Zn	0.27	0.11	0.05	Zn	0.21	0.09	0.04
	PO_4	63.2	58.4	23.8	PO_4	13.3	12.7	5.2
	NO_3	2.9	0.96	0.39	NO_3	2.5	0.76	0.31

Means and Standard Deviations of Soil Nutrient Concentrations
(Micrograms/Gram, Parts per Million for Nitrate)

Drainage Classification B

	Andic Layer				Subsoil Layer			
Drainage Class	Category	Mean	Standard Deviation	Standard Error	Category	Mean	Standard Deviation	Standard Error
Slow	Ca	752	155	77.7	Ca	761	99.9	50.0
	Cu	1.4	0.32	0.16	Cu	2.1	0.36	0.18
	Fe	4.0	0.41	0.21	Fe	2.1	0.80	0.18
	K	123	37.5	18.8	K	53.9	8.4	4.2
	Mg	52.8	5.1	2.5	Mg	122	31.2	15.6
	Mn	6.9	2.1	1.1	Mn	3.4	0.81	0.41
	Na	21.6	6.0	3.0	Na	17.7	0.83	0.41
	Zn	0.39	0.02	0.01	Zn	0.40	0.07	0.35
	PO_4	91.1	25.4	12.7	PO_4	3.3	1.9	0.93
	NO_3	3.6	0.84	0.42	NO_3	2.4	0.70	0.35
Moderate	Ca	745	303	87.5	Ca	689	265	76.5
	Cu	1.5	0.43	0.13	Cu	1.91	0.46	0.13
	Fe	3.8	1.2	0.36	Fe	2.0	1.5	0.45
	K	146	39.8	11.5	K	38.8	16.2	4.7
	Mg	41.9	14.1	4.1	Mg	67.5	27.2	7.8
	Mn	9.1	2.4	0.70	Mn	1.5	0.81	0.23
	Na	23.6	8.9	2.6	Na	15.0	6.5	1.9
	Zn	0.35	0.21	0.06	Zn	0.31	0.16	0.05
	PO_4	46.2	41.9	12.1	PO_4	9.2	9.7	2.8
	NO_3	3.0	0.67	0.19	NO_3	2.5	0.49	0.14
Rapid	Ca	811	327	189	Ca	882	71.7	41.4
	Cu	1.3	0.27	0.15	Cu	1.6	0.35	0.20
	Fe	6.1	2.0	1.1	Fe	3.2	1.9	1.1
	K	148	68.6	39.6	K	43.8	16.6	9.6
	Mg	48.4	19.7	11.4	Mg	67.3	20.0	11.5
	Mn	9.8	6.5	3.8	Mn	2.1	1.4	0.80
	Na	14.6	1.6	0.92	Na	11.8	1.4	0.83
	Zn	0.34	0.10	0.06	Zn	0.27	0.06	0.04
	PO_4	64.4	72.1	41.7	PO_4	21.4	14.1	8.1
	NO_3	2.9	1.4	0.78	NO_3	2.9	1.0	0.58

Means and Standard Deviations of Soil Nutrient Concentrations
(Micrograms/Gram, Parts per Million for Nitrate)

Land Type Classification

	Andic Layer				Subsoil Layer			
Land Type Class	Category	Mean	Standard Deviation	Standard Error	Category	Mean	Standard Deviation	Standard Error
351	Ca	752	155	77.7	Ca	761	99.9	50.0
	Cu	1.4	0.32	0.16	Cu	2.1	0.36	0.18
	Fe	4.0	0.41	0.21	Fe	2.1	0.80	0.40
	K	123	37.5	18.8	K	53.9	8.4	4.2
	Mg	52.8	5.1	2.5	Mg	122	31.2	15.6
	Mn	6.9	2.1	1.1	Mn	3.4	0.81	0.41
	Na	21.6	6.0	3.0	Na	17.7	0.83	0.41
	Zn	0.39	0.02	0.01	Zn	0.40	0/07	0.04
	PO_4	91.1	25.4	12.7	PO_4	3.3	1.9	0.93
	NO_3	3.6	0.84	0.42	NO_3	2.4	0.70	0.35
352	Ca	691	337	119	Ca	702	255	90.2
	Cu	1.5	0.5	0.19	Cu	2.0	0.51	0.18
	Fe	3.4	1.3	0.46	Fe	2.4	1.8	0.62
	K	135	33.9	12.0	K	32.7	5.5	1.9
	Mg	37.5	9.5	3.4	Mg	61.0	27.8	9.8
	Mn	9.9	1.6	0.58	Mn	1.6	0.81	0.29
	Na	27.1	9.0	3.2	Na	16.8	7.4	2.6
	Zn	0.41	0.23	0.09	Zn	0.38	0.14	0.05
	PO_4	40.4	40.9	14.4	PO_4	11.1	11.6	4.1
	NO_3	3.1	0.74	0.26	NO_3	2.7	0.50	0.18
355	Ca	836	246	92.8	Ca	758	260	98.1
	Cu	1.4	0.20	0.07	Cu	1.6	0.26	0.10
	Fe	5.2	1.5	0.58	Fe	2.1	1.5	0.59
	K	160	52.5	19.8	K	47.9	20.1	7.6
	Mg	49.7	17.8	6.7	Mg	74.9	21.5	8.1
	Mn	8.5	4.6	1.7	Mn	1.6	1.1	0.42
	Na	15.7	1.7	0.63	Na	11.6	1.2	0.45
	Zn	0.28	0.10	0.04	Zn	0.21	0.09	0.03
	PO_4	60.7	53.7	20.3	PO_4	12.1	12.0	4.5
	NO_3	2.8	0.88	0.33	NO_3	2.4	0.71	0.27

Means and Standard Deviations of Soil Nutrient Availabilities

(Milliequivalents/Square Meter, Parts per Million for Nitrate)

Drainage Classification A

	Andic Layer				Subsoil Layer			
Drainage Class	Category	Mean	Standard Deviation	Standard Error	Category	Mean	Standard Deviation	Standard Error
Slow	Ca	8755	3101	1266	Ca	40671	8425	3439
	Cu	12.8	6.9	2.8	Cu	76.2	24.1	9.9
	Fe	46.5	14.5	5.9	Fe	106	40.9	16.7
	K	826	282	115	K	1348	402	164
	Mg	1038	335	137	Mg	9535	4518	1845
	Mn	76.7	32.6	13.3	Mn	123	53.1	21.7
	Na	248	55.7	22.8	Na	790	204	83.2
	Zn	3.5	2.1	0.85	Zn	13.5	5.3	2.2
	PO_4	628	425	173	PO_4	265	367	150
	Total Cations	11007	3608	1473	Total Cations	52661	13231	5402
	NO_3	3.2	0.89	0.36	NO_3	2.4	0.58	0.24
Moderate	Ca	11042	5592	2114	Ca	37034	16079	6077
	Cu	13.1	2.9	1.1	Cu	64.7	13.0	4.9
	Fe	43.6	17.5	6.6	Fe	105	82.4	31.1
	K	1069	350	132	K	1065	536	202
	Mg	991	·476	180	Mg	5694	2774	1049
	Mn	93.6	22.0	8.3	Mn	52.6	31.5	11.9
	Na	320	143	54.0	Na	808	374	141
	Zn	3.1	1.3	0.51	Zn	11.9	4.6	1.7
	PO_4	366	355	134	PO_4	251	186	70.2
	Total Cations	13575	6075	2296	Total Cations	44834	17629	6663
	NO_3	3.1	0.68	0.26	NO_3	2.7	0.54	0.20
Rapid	Ca	12507	2731	1115	Ca	30096	19319	7887
	Cu	13.0	2.8	1.1	Cu	40.7	23.6	9.6
	Fe	78.3	44.9	18.3	Fe	68.0	37.3	15.2
	K	1155	260	106	K	935	878	358
	Mg	1218	698	285	Mg	5427	4152	1695
	Mn	103	50.7	20.7	Mn	49.5	39.1	16.0
	Na	214	46.0	18.8	Na	398	235	96.0
	Zn	2.5	0.84	0.34	Zn	4.8	3.5	1.4
	PO_4	593	482	197	PO_4	235	124	50.8
	Total Cations	15290	3052	1246	Total Cations	37019	22853	9330
	NO_3	2.9	0.96	0.39	NO_3	2.5	0.74	0.30

Means and Standard Deviations of Soil Nutrient Availabilities
(Milliequivalents/Square Meter, Parts per Million for Nitrate)

Drainage Classification B

Drainage Class	Andic Layer Category	Mean	Standard Deviation	Standard Error	Subsoil Layer Category	Mean	Standard Deviation	Standard Error
Slow	Ca	9813	3398	1699	Ca	44248	8040	4020
	Cu	12.3	5.9	2.9	Cu	77.5	18.6	9.3
	Fe	46.8	14.1	7.1	Fe	113	49.9	25.0
	K	834	354	177	K	1590	186	93.0
	Mg	1133	368	184	Mg	11777	3622	1811
	Mn	69.0	38.6	19.3	Mn	145	42.5	21.2
	Na	231	43.4	21.7	Na	899	135	67.7
	Zn	3.3	0.96	0.48	Zn	14.0	4.2	2.1
	PO_4	790	433	216	PO_4	121	77.3	38.7
	Total Cations	12142	4060	2030	Total Cations	58861	11720	5860
	NO_3	3.5	0.83	0.41	NO_3	2.4	0.70	0.35
Moderate	Ca	10689	4753	1372	Ca	35645	16338	4716
	Cu	13.3	4.4	1.3	Cu	62.1	20.7	6.0
	Fe	48.3	17.0	4.9	Fe	94.5	67.4	19.5
	K	1050	306	88.2	K	1088	676	195
	Mg	974	371	107	Mg	6002	3114	899
	Mn	92.6	22.3	6.5	Mn	60.1	38.0	11.0
	Na	289	117	33.8	Na	689	339	97.8
	Zn	3.0	1.8	0.52	Zn	10.1	5.8	1.7
	PO_4	409	355	103	PO_4	279	277	79.8
	Total Cations	13159	5131	1481	Total Cations	43649	18260	5271
	NO_3	3.0	0.67	0.19	NO_3	2.5	0.49	0.14
Rapid	Ca	12451	3209	1853	Ca	26368	14794	8541
	Cu	12.7	1.2	0.67	Cu	33.0	27.1	15.6
	Fe	96.0	63.2	36.5	Fe	65.0	14.8	8.5
	K	1143	338	195	K	580	93.1	53.8
	Mg	1416	1034	597	Mg	3501	2628	1517
	Mn	115	69.1	39.9	Mn	34.0	13.1	7.6
	Na	208	69.2	40.0	Na	308	178	103
	Zn	3.0	0.0	0.0	Zn	5.3	4.2	2.4
	PO_4	607	580	335	PO_4	307	83.7	48.3
	Total Cations	15446	3906	2255	Total Cations	30894	17591	10156
	NO_3	2.9	1.4	0.78	NO_3	2.9	0.95	0.55

Means and Standard Deviations of Soil Nutrient Availabilities
(Milliequivalents/Square Meter, Parts per Million for Nitrate)

Land Type Classification

	Andic Layer				Subsoil Layer			
Land Type Class	Category	Mean	Standard Deviation	Standard Error	Category	Mean	Standard Deviation	Standard Error
351	Ca	9813	3398	1699	Ca	44248	8040	4020
	Cu	12.3	5.9	2.9	Cu	77.5	18.6	9.3
	Fe	46.8	14.1	7.1	Fe	113	49.9	25.0
	K	834	354	177	K	1590	186	93.0
	Mg	1133	368	184	Mg	11777	3622	1811
	Mn	69.0	38.6	19.3	Mn	145	42.5	21.2
	Na	231	43.4	21.7	Na	899	135	67.7
	Zn	3.2	0.96	0.48	Zn	14.0	4.2	2.1
	PO_4	790	433	216	PO_4	121	77.3	38.7
	Total Cations	12142	4060	2030	Total Cations	58861	11720	5860
	NO_3	3.5	0.83	0.41	NO_3	2.4	0.70	0.35
352	Ca	9622	5395	1907	Ca	37020	14810	5236
	Cu	13.3	5.1	1.8	Cu	66.8	20.7	7.3
	Fe	41.9	16.7	5.9	Fe	109	74.3	26.3
	K	927	224	79.2	K	878	220	78.0
	Mg	832	200	70.6	Mg	5265	2488	880
	Mn	97.6	15.3	5.4	Mn	63.0	34.7	12.3
	Na	324	131	46.3	Na	768	364	129
	Zn	3.4	2.1	0.73	Zn	12.4	5.4	1.9
	PO_4	339	332	118	PO_4	332	325	115
	Total Cations	11862	5716	2021	Total Cations	44182	16430	5809
	NO_3	3.1	0.74	0.26	NO_3	2.7	0.50	0.18
355	Ca	12663	2527	955	Ca	30097	17636	6666
	Cu	13.1	2.5	0.96	Cu	44.3	23.6	8.9
	Fe	76.0	41.5	15.7	Fe	65.9	34.5	13.0
	K	1230	311	118	K	1109	924	349
	Mg	1326	699	264	Mg	5772	3898	1473
	Mn	96.4	49.3	18.6	Mn	45.6	37.1	14.0
	Na	214	42.0	15.9	Na	435	236	89.0
	Zn	2.6	0.79	0.30	Zn	5.4	3.6	1.3
	PO_4	574	442	167	PO_4	230	114	43.2
	Total Cations	15621	2920	1104	Total Cations	37574	20914	7905
	NO_3	2.8	0.88	0.33	NO_3	2.5	0.70	0.26

Means and Standard Deviations of Soil Nutrient Availabilities
(Kilograms/Hectare)

Drainage Classification A

Drainage Class	Andic Layer Category	Mean	Standard Deviation	Standard Error	Subsoil Layer Category	Mean	Standard Deviation	Standard Error
Slow	Ca	2248	1276	521	Ca	4015	1740	711
	Cu	4.3	1.7	0.69	Cu	10.8	3.5	1.4
	Fe	14.7	10.9	4.5	Fe	12.0	7.8	3.2
	K	420	313	128	K	263	120	49.0
	Mg	184	147	60.1	Mg	609	398	162
	Mn	83.9	160	65.0	Mn	16.0	10.0	4.1
	Na	65.3	29.4	12.0	Na	87.2	36.1	14.7
	Zn	1.8	1.4	0.56	Zn	2.0	1.1	0.43
	PO_4	385	445	182	PO_4	44.4	64.1	26.2
	Total N	2600	1891	772	Total N	939	381	156
Moderate	Ca	2227	1363	515	Ca	3149	2102	794
	Cu	4.3	1.7	0.63	Cu	8.7	3.8	1.4
	Fe	10.5	4.5	1.7	Fe	8.7	5.2	2.0
	K	434	180	68.1	K	169	80.1	30.3
	Mg	140	68.0	25.7	Mg	314	285	108
	Mn	66.5	78.5	29.7	Mn	6.4	4.4	1.7
	Na	84.0	68.5	25.9	Na	86.8	75.5	28.5
	Zn	1.5	0.85	0.32	Zn	1.7	1.1	0.41
	PO_4	255	299	113	PO_4	31.5	25.9	9.8
	Total N	2193	844	319	Total N	565	267	101
Rapid	Ca	2434	1948	795	Ca	1906	1079	440
	Cu	3.7	2.1	0.86	Cu	3.8	2.1	0.87
	Fe	14.4	9.4	3.9	Fe	4.6	2.7	1.1
	K	364	194	78.9	K	133	170	69.3
	Mg	139	99.9	40.8	Mg	202	158	64.7
	Mn	37.0	31.5	12.9	Mn	4.6	3.7	1.5
	Na	44.1	27.2	11.1	Na	27.8	18.0	7.4
	Zn	0.90	0.53	0.22	Zn	0.42	0.23	0.10
	PO_4	126	72.5	29.6	PO_4	20.8	9.1	3.7
	Total N	2231	1796	733	Total N	451	268	110

Means and Standard Deviations of Soil Nutrient Availabilities
(Kilograms/Hectare)

Drainage Classification B

Drainage Class	Andic Layer Category	Mean	Standard Deviation	Standard Error	Subsoil Layer Category	Mean	Standard Deviation	Standard Error
Slow	Ca	1935	695	348	Ca	4677	1731	865
	Cu	3.6	1.6	0.78	Cu	11.9	3.9	1.9
	Fe	10.5	3.4	1.7	Fe	14.2	9.0	4.5
	K	333	173	86.7	K	324	88.8	44.4
	Mg	134	48.2	24.1	Mg	782	364	182
	Mn	18.1	9.0	4.5	Mn	20.3	9.5	4.8
	Na	52.2	15.3	7.7	Na	104	30.5	15.3
	Zn	0.95	0.25	0.13	Zn	2.3	1.2	0.60
	PO_4	244	133	66.6	PO_4	21.2	19.2	9.6
	Total N	1933	626	313	Total N	1099	331	166
Moderate	Ca	2600	1733	500	Ca	2915	1700	491
	Cu	4.7	1.7	0.49	Cu	7.8	3.2	0.9
	Fe	14.1	9.4	2.7	Fe	7.7	4.4	1.3
	K	470	244	70.4	K	176	118	34.1
	Mg	168	117	33.9	Mg	302	231	66.7
	Mn	86.3	120	34.5	Mn	6.5	4.0	1.1
	Na	78.7	55.2	15.9	Na	69.3	60.6	17.5
	Zn	1.7	1.1	0.33	Zn	1.3	0.96	0.28
	PO_4	293	383	111	PO_4	38.5	46.8	13.5
	Total N	2644	1704	492	Total N	574	266	76.8
Rapid	Ca	1581	623	359	Ca	1294	269	155
	Cu	2.5	0.87	0.50	Cu	2.1	0.93	0.54
	Fe	12.3	9.6	5.5	Fe	3.8	2.0	1.1
	K	256	59.0	34.1	K	51.9	9.4	5.4
	Mg	121	119	68.6	Mg	104	50.3	29.0
	Mn	27.8	21.4	12.3	Mn	3.1	2.4	1.4
	Na	30.4	18.1	10.5	Na	15.9	3.9	2.2
	Zn	0.83	0.49	0.29	Zn	0.33	0.15	0.09
	PO_4	117	85.7	49.5	PO_4	21.6	9.3	5.3
	Total N	1622	1112	642	Total N	338	125	72.3

Means and Standard Deviations of Soil Nutrient Availabilities
(Kilograms/Hectare)

Land Type Classification

	Andic Layer				Subsoil Layer			
Land Type Class	Category	Mean	Standard Deviation	Standard Error	Category	Mean	Standard Deviation	Standard Error
351	Ca	1935	695	348	Ca	4677	1731	865
	Cu	3.6	1.6	0.78	Cu	11.9	3.9	1.9
	Fe	10.5	3.4	1.7	Fe	14.2	9.0	4.5
	K	333	173	86.7	K	324	88.8	44.4
	Mg	134	48.2	24.1	Mg	782	364	182
	Mn	18.1	9.0	4.5	Mn	20.3	9.5	4.8
	Na	52.2	15.3	7.7	Na	104	30.5	15.3
	Zn	0.95	0.25	0.13	Zn	2.3	1.2	0.59
	PO_4	244	133	66.6	PO_4	21.2	19.2	9.6
	Total N	1933	626	313	Total N	1099	331	166
352	Ca	2427	1563	553	Ca	2962	2149	877
	Cu	4.8	1.6	0.56	Cu	8.3	2.9	1.2
	Fe	13.8	10.1	3.6	Fe	8.2	4.0	1.6
	K	468	279	98.6	K	150	87.4	35.7
	Mg	172	137	48.4	Mg	326	310	126
	Mn	111	140	49.7	Mn	6.2	3.8	1.5
	Na	91.9	62.2	22.0	Na	79.9	81.0	33.1
	Zn	2.1	1.2	0.42	Zn	1.5	0.94	0.38
	PO_4	377	452	160	PO_4	58.5	61.9	25.3
	Total N	2700	1661	587	Total N	616	312	127
355	Ca	2361	1788	676	Ca	1849	996	377
	Cu	3.6	1.9	0.74	Cu	4.0	2.0	0.76
	Fe	13.8	8.8	3.3	Fe	4.4	2.5	0.95
	K	379	181	68.5	K	144	158	59.6
	Mg	144	92.1	34.8	Mg	207	145	54.9
	Mn	33.2	30.5	11.5	Mn	4.1	3.6	1.3
	Na	42.9	25.0	9.5	Na	29.2	16.9	6.4
	Zn	0.87	0.49	0.19	Zn	0.46	0.24	0.09
	PO_4	122	66.9	25.3	PO_4	20.1	8.5	3.2
	Total N	2143	1656	626	Total N	451	245	92.6

APPENDIX 16

Means and Standard Deviations of Site Productivity Data

1. Means and Standard Deviations of Site Tree Data.
2. Means and Standard Deviations of Xylem Sap Nutrient Concentrations (Milligrams/Liter).
3. Means and Standard Deviations of Moisture Stress Measurements (MegaPascals).

1. Means and Standard Deviations of Site Tree Data.

Means and Standard Deviations of Site Tree Data

Classification System	Division	Category	Mean	Standard Deviation	Standard Error
Drainage Classification A	Slow	SA/BA	0.42	0.07	0.01
		IRI	12.4	3.2	0.49
		ORI	19.6	4.7	0.72
		SI	64.3	7.3	1.1
	Moderate	SA/BA	0.41	0.08	0.01
		IRI	13.8	3.3	0.48
		ORI	16.3	3.2	0.46
		SI	68.6	7.4	1.1
	Rapid	SA/BA	0.42	0.07	0.01
		IRI	13.6	3.6	0.56
		ORI	15.5	3.8	0.58
		SI	67.7	9.6	1.5
Drainage Classification B	Slow	SA/BA	0.44	0.06	0.01
		IRI	11.1	2.1	0.40
		ORI	21.4	3.9	0.74
		SI	64.5	7.8	0.85
	Moderate	SA/BA	0.41	0.08	0.01
		IRI	13.6	3.5	0.38
		ORI	16.4	3.3	0.37
		SI	67.5	7.8	0.85
	Rapid	SA/BA	0.40	0.08	0.02
		IRI	15.2	3.2	0.70
		ORI	13.8	3.4	0.74
		SI	67.9	11.5	2.5
Land Type Classification	351	SA/BA	0.44	0.06	0.01
		IRI	11.1	2.1	0.40
		ORI	21.4	3.9	0.74
		SI	64.5	6.6	1.3
	352	SA/BA	0.40	0.08	0.01
		IRI	14.4	3.2	0.43
		ORI	15.9	3.2	0.43
		SI	67.4	8.3	1.1
	355	SA/BA	0.42	0.07	0.01
		IRI	13.3	3.7	0.52
		ORI	15.9	3.8	0.54
		SI	67.8	8.9	1.3

SA/BA = Sapwood Area/Basal Area IRI = Inner Rings/2.54 cm
ORI = Outer Rings/2.54 cm SI = Site Index

2. Means and Standard Deviations of Xylem Sap Nutrient Concentrations (Milligrams/Liter).

Means and Standard Deviations of Xylem Sap Nutrient Concentrations
(Milligrams/Liter)

Drainage Class	Drainage Classification A: Category	Mean	Standard Deviation	Standard Error	Drainage Classification B: Category	Mean	Standard Deviation	Standard Error
Slow	Ca	2.89	0.87	0.23	Ca	2.82	0.91	0.28
	Cu	0.62	0.28	0.07	Cu	0.69	0.27	0.08
	Fe	0.13	0.10	0.03	Fe	0.10	0.06	0.02
	K	34.7	14.9	3.99	K	35.5	16.8	5.07
	Mg	1.71	0.44	0.12	Mg	1.68	0.45	0.14
	Mn	0.32	0.11	0.03	Mn	0.30	0/07	0.02
	Na	1.75	1.11	0.30	Na	1.93	1.16	0.35
	Zn	0.40	0.27	0.07	Zn	0.46	0.29	0.09
	PO_4	0.53	0.21	0.06	PO_4	0.51	0.22	0.07
	Total N	69.0	15.8	4.22	Total N	70.0	17.5	5.28
Moderate	Ca	2.59	0.74	0.23	Ca	2.58	0.76	0.18
	Cu	0.65	0.16	0.05	Cu	0.61	0.18	0.04
	Fe	0.16	0.07	0.02	Fe	0.16	0.09	0.02
	K	25.2	5.44	1.72	K	26.3	5.17	1.26
	Mg	1.53	0.41	0.13	Mg	1.49	0.42	0.10
	Mn	0.41	0.12	0.04	Mn	0.39	0.14	0.03
	Na	1.29	0.67	0.21	Na	1.25	0.66	0.16
	Zn	0.26	0.20	0.06	Zn	0.29	0.19	0.05
	PO_4	0.49	0.17	0.05	PO_4	0.45	0.19	0.05
	Total N	62.7	25.8	8.17	Total N	68.1	24.9	6.05
Rapid	Ca	2.25	0.61	0.25	Ca	2.50	0.71	0.50
	Cu	0.65	0.12	0.05	Cu	0.57	0.09	0.07
	Fe	0.13	0.10	0.04	Fe	0.25	0.00	0.00
	K	22.6	4.91	2.01	K	17.7	3.75	2.65
	Mg	2.26	2.82	1.15	Mg	4.44	5.04	3.56
	Mn	0.35	0.15	0.06	Mn	0.35	0.21	0.15
	Na	1.34	0.76	0.31	Na	1.44	0.79	0.56
	Zn	0.33	0.21	0.09	Zn	0.16	0.05	0.04
	PO_4	0.31	0.09	0.04	PO_4	0.38	0.05	0.04
	Total N	82.3	30.7	12.5	Total N	78.8	47.0	33.3

Means and Standard Deviations of Xylem Sap Nutrient Concentrations (Milligrams/Liter)

Land Type Classification

Land Type Class	Category	Mean	Standard Deviation	Standard Error
351	Ca	2.82	0.91	0.28
	Cu	0.69	0.27	0.08
	Fe	0.10	0.06	0.02
	K	35.5	16.8	5.07
	Mg	1.68	0.45	0.14
	Mn	0.30	0.07	0.02
	Na	1.93	1.16	0.35
	Zn	0.46	0.28	0.09
	PO_4	0.51	0.22	0.07
	Total N	70.0	17.5	5.28
352	Ca	2.74	0.69	0.23
	Cu	0.51	0.17	0.06
	Fe	0.20	0.09	0.03
	K	29.1	2.99	1.00
	Mg	1.62	0.43	0.14
	Mn	0.37	0.15	0.05
	Na	1.17	0.69	0.23
	Zn	0.16	0.06	0.02
	PO_4	0.50	0.15	0.05
	Total N	54.4	16.7	5.57
355	Ca	2.42	0.77	0.24
	Cu	0.69	0.12	0.04
	Fe	0.14	0.09	0.03
	K	22.0	5.47	1.73
	Mg	1.97	2.15	0.68
	Mn	0.40	0.13	0.04
	Na	1.36	0.64	0.20
	Zn	0.37	0.21	0.07
	PO_4	0.40	0.20	0.06
	Total N	82.6	26.6	8.42

3. Means and Standard Deviations of Moisture Stress Measurements (megaPascals).

Means and Standard Deviations of Moisture Stress
Measurements (MegaPascals)

Classification System	Division	Category	Mean	Standard Deviation	Standard Error
Drainage Classification A	Slow	Stress	1.52	0.69	0.13
	Moderate	Stress	1.89	0.59	0.09
	Rapid	Stress	2.03	0.42	0.07
Drainage Classification B	Slow	Stress	1.24	0.32	0.08
	Moderate	Stress	1.90	0.62	0.07
	Rapid	Stress	2.09	0.29	0.07
Land Type Classification	351	Stress	1.24	0.32	0.08
	352	Stress	1.90	0.68	0.10
	355	Stress	2.00	0.41	0.07

APPENDIX 17

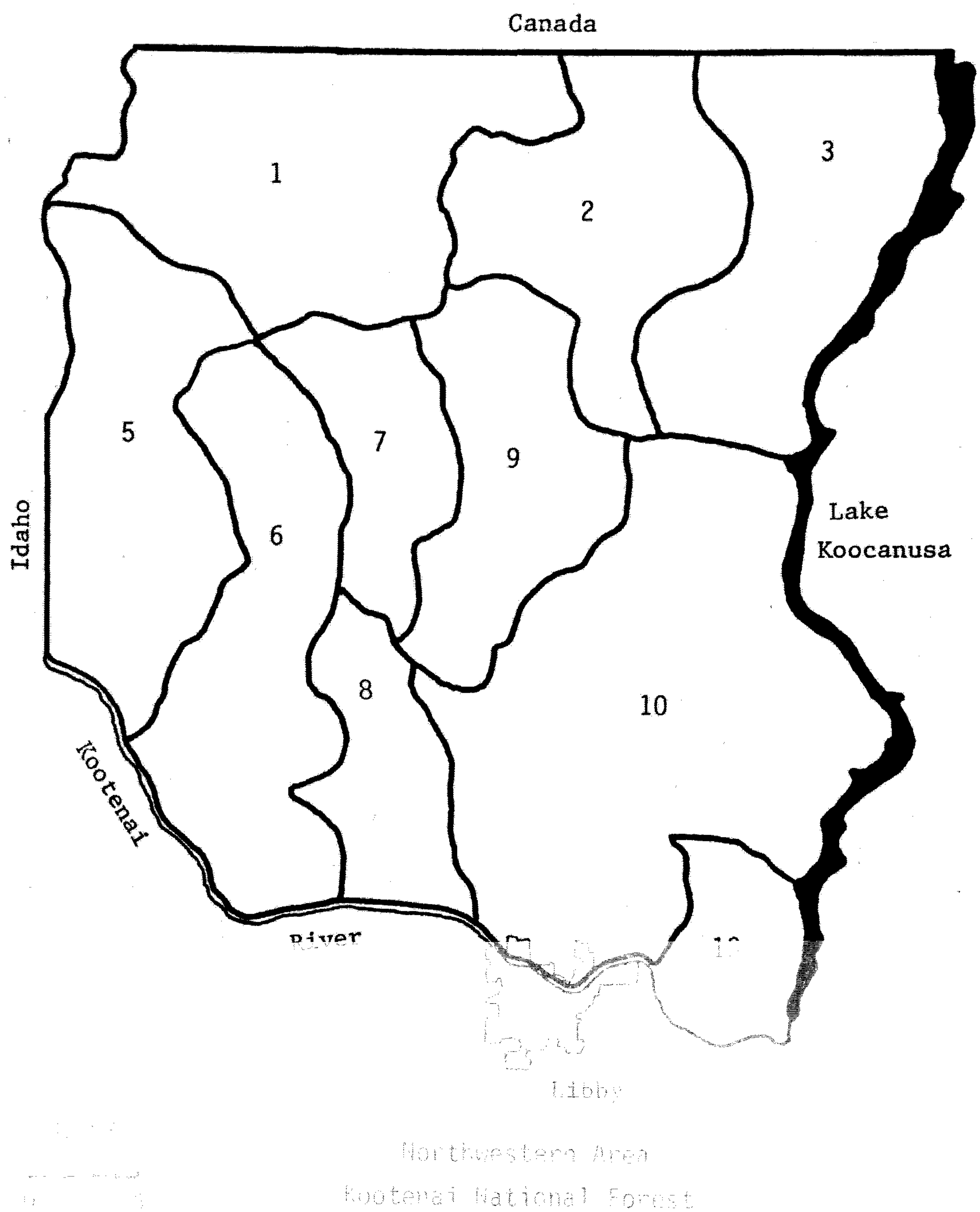
Precipitation Determination

1. Precipitation: Runoff vs Elevation Zone (Map).
2. Precipitation vs elevation (Graph) for the Quartz region of the Kootenai National Forest.

(From the U.S. Forest Service, Kootenai National Forest)

1. Precipitation: Runoff vs Elevation Zone (Map).

Figure 1. Precipitation: Runoff vs Elevation Zone
Used to determine precipitation on the Kootenai National Forest. Zone 8 (Quartz Region) is applicable to the study sites.



2. Precipitation vs elevation for the Quartz region of the Kootenai National Forest.

2. Precipitation vs elevation for the Quartz region of the Kootenai National Forest.